HOT IN-PLACE RECYCLING OF ASPHALT PAVEMENTS

An Engineering Report
by
Michael Lawrence Dowdy

Submitted to the Graduate College of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF ENGINEERING

4 August 1987

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ABSTRACT

The purpose of this report is to identify factors to consider in selecting a hot in-place recycling project for asphalt pavements. This type of asphalt pavement recycling process is becoming very popular.

This report discusses the different types of recycling processes and several selected hot in-place recycling processes that are becoming so popular today. The types of asphalt pavement distress and their causes are discussed to provide a working knowledge of possible applications for this process. Discussions on project selection, design, and construction considerations will also provide an awareness of considerations relative to this type of asphalt pavement rehabilitation. An understanding of these topics will be helpful when selecting hot in-place recycling.

The information that this report is based upon was obtained from various sources. A literature search included technical reports, periodicals, and advertisements. Personal contact was made in the form of interviews with a number of representatives in the industry and on site inspection of Cutler Repaving, Inc. and Remixer Contracting Co., Inc. operations.

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I. INTRODUCTION

We are a wasteful society! The phrases "non returnable" and "disposable" are on many products in every market today. When something is no longer of need or value we simply throw it away. However, many products can and have been recycled or reused in an economical manner. These include such items as aluminum cans, newspapers, junk cars, and asphalt pavements.

The United States (U.S.) has had tremendous industrial and economic growth during this century. This growth has created 'shortages' of materials and energy. These shortages are a result of inadequate supply of resources, or the failure to develop new material sources as fast as required by our economy. Continued development of raw materials is not always enough. In order to maintain our present standard of living, we must keep costs down. Recycling is one way of reducing the escalating cost impact of new materials.

In highway construction, contractors and governmental agencies have been wasteful of materials and energy. Because of an abundant and cheap supply of new materials, recycling was not deemed necessary. It is common to see stretches of abandoned highways running along a newer roadway. Old pavements quite often end up in landfills, in ditches to control erosion, or along side of the roadways making big piles of ugly rubble. The old pavement materials are still valuable construction materials in which much money and energy have been invested.

"The highway system in this country represents a total capital investment of about $275 billion....Over three quarters of that investment [$275 billion], or about $210 billion, has been made since the beginning of the interstate program in 1965" (Noel, 1980).

In the past, most roadway construction was for new roadways which required lots of new materials. Today, a large percentage of the roadway construction is rehabilitation of old roadways. According to Noel, as of 1980 the current annual rate of expenditure for capital improvements was about $14 billion of which 30 to 40 percent went for pavement structure improvements.

Statistics show that our impressive network of highways, county roads,and city streets are gradually deteriorating despite the enormous amount of revenues pumped into roadway rehabilitation. Over the last twenty years an unprecedented amount of roadway construction took place. Many of these pavements are now in need of repair as they approach the end of their design life. Thus, the rate of deterioration will continue to increase alarming. Deterioration of roadways is one of the most critical and frustrating problems facing highway administrators and city and county public works officials.

There are several approaches to solving these deterioration problems: better roadway designs for the future, reducing traffic on existing roads, allocating more funds for rehabilitation, or reducing rehabilitation costs. We are not likely to see any 'cure all' roadway design breakthroughs in the near future. Even if we did, that would not help the situation today. Decreasing the amount of roadway traffic to slow down the rate of deterioration is not very practical. Very few of us would be willing to throw away our automobiles and airplane tickets in exchange for train tickets. The U.S. Department of Transportation's Highway Statistics Summary to 1987 estimates that there will be over 1.8 trillion annual vehicle miles of travel compared to 1.5 in 1980 and 1.1 in 1970. Increased funding for roadway rehabilitation to adequately correct our deterioration woes is not likely without higher taxes or cuts within other departments or agencies. Consequently, trading-off higher taxes in lieu of budget cuts in other areas for an adequate increase in funding is not very appealing, in view of the consequences. Rehabilitation costs have increased dramatically because of inflation created by shortages and oil embargos. "The Federal Highway Administration's construction cost index has increased more rapidly than the consumer price index since 1967" (Lahue, 1980). Thus, lower rehabilitation costs do not seem likely either. So where does that leave us? The answer is that we must use our rehabilitation funds wisely and find ways to stretch those funds.

Pavement recycling is one rehabilitation method available that can help us cut costs. Recycling is becoming more popular every day. However, recycling is not a new idea. "The first printed mention or recycling goes back ...., to a 1915 Warren Brothers' sales brochure for their new Portable Asphalt Plant. The contracting firm claimed that the machine heated and reworked existing sheet asphalt pavements with excellent results and considerable savings in costs of the resultant mix" (Public Works, May 1979). This was perhaps the first drum mixer. During the 1920's and 1930's a common type of rehabilitation called 'reconstruction' was very similar to hot in-place recycling. Since then, recycling across the country has been sporadic. However, there has been a history of recycling experience in the Pittsburgh, Pennsylvania, area dating back to 1953 when it "reclaimed old pavements using aromatic asphalt conditioners.... Much of this pavement still exists in good condition and remains in active use" (Gaetano and O'Mara, 1980). It was not until the mid 1970's that recycling really began to be seriously considered as a rehabilitation alternative across most of the nation.

Recycling of asphalt pavements has proven to be a viable rehabilitation alternative. More and more agencies and public works departments are considering, allowing, and even specifying recycling of one kind or another.

II. MATERIAL AVAILABILITY

The law of conservation of matter dictates that matter can neither be created nor destroyed; only the form can be altered. "Alterations through use reduces the availability of certain forms of matter and thereby creates 'shortages' of matter in the form desired at a given time" (Marek and Jones, 1976).

There are two kinds of shortages, artificial and real. An artificial shortage is where a material is in the wrong form or wrong place at the time of need for it to be obtained economically. The other kind of shortage is that which is real and is caused by depletion of the resources. The impact of these shortages can be decreased by long range planning, changing of goals, policies, attitudes, good land use, recycling of old materials, and material substitutions.

In general, quality construction materials are in abundant supply for the future in the U.S. Numerous sources state that we have an infinite supply of aggregates, cement materials, and lime. Estimates for the number of years of remaining availability for asphalt and other road oils are between 90 and 200 years. New technology and developments will continue to make more materials available as these artificial shortages produce demands for more materials and real shortages produce demands for replacement materials.

However, in some areas there is a lack of good quality construction materials. Material supply problems have resulted from mining restrictions, environmental regulations, increasing haul distances, and increasing land and transportation costs. Rising energy costs have had a significant impact on driving up the cost of obtaining construction materials. As if this was not enough, labor costs have continued to climb. Environmental regulations have created problems in mining new materials and disposing of old materials. Sources for construction materials near the large urban areas (where most of these materials are used) are running low or are presently inaccessible due to higher land costs, developments, and zoning restrictions. All of this only means that presently accessible supplies will be more remote and more expensive.

The highway industry does have some advantages to all of these problems. There is an estimated 15 billion tons of recyclable pavement in the so called 'Asphalt Bank,' which is rich in high grade asphalt and aggregates valued at over $50 billion. These old pavements have been overlaid, sealed, etc. until they have accumulated between 1/2 to 24 inches or more of good asphalt and aggregates, not to mention the underlying base material and any portland cement concrete slabs in place.

The energy crisis was the 'spark' that started the recycling movement in the highway construction business. Asphalt pavement recycling is an alternative for roadway rehabilitation that can cut the amount of new materials and energy needed. This in turn will cut asphalt pavement rehabilitation costs. Cutting cost is needed to maintain the pace of roadway rehabilitation. New technology has helped make recycling economical today by making it possible to reuse existing materials to produce suitable pavements.

III. TYPES OF RECYCLING OPERATIONS

A. General

Asphalt pavement recycling operations are categorized in different ways. Some people and organizations list the categories as surface, cold, and hot recycling. Others use the more popular categories of surface, in-place, and central plant recycling. This report will use the later.

The following discussion will provide a familiarization of the various recycling techniques within each category. A better understanding of these techniques will enable a more informed selection for the purpose of rehabilitating roadway distress.

B. Surface Recycling

1. General

Surface recycling is defined as the "reworking of the surface of a pavement to a depth of less than about 1 in. by heater planer, heater scarifier,hot milling, cold planing, or cold milling devices. This operation is a continuous, single pass, multistage process that may involve use of new materials, including aggregate, modifiers, or mixtures" (Monismith, 1981). Another definition is "one of several methods where the surface of an existing asphalt pavement is planed, milled, or heated in place. In the latter case the pavement may be scarified, remixed, relaid, and rolled. Additionally, asphalt, softening agents,minimal amounts of new asphalt hot mix, aggregate, or combination of these may be added to obtain desirable mixture and surface

characteristics. The finished product may be used as the finished surface or may, in some instances, be overlayed with an asphalt surface course" (Epps, 1980). These two definitions are provided to show that some specify surface recycling as rehabilitating the top 1 inch of pavement and others do not.

The first definition above listed six techniques of surface recycling. It may be more appropriate to categorize these techniques as surface removal and surface reworking.

2. Surface Removal Processes

The surface removal processes are heater planer, hot milling, cold planing, and cold milling. All of these processes are generally used for the same reasons. Some of their uses are to maintain pavement grade and slope, remove pavement from bridge decks, maintain clearances in tunnels and under highway structures like overpasses and sign bridges, remove seal coats, and remove pavement irregularities like ruts, shoving, flushing, and polished aggregates. They are often used prior to asphalt pavement overlays to correct surface irregularities, maintain roadway design, and improve bonding between the existing pavement and overlay.

These processes are not true surface recycling processes, rather they are simply surface removal process. They are used to remove asphalt pavement surface material which can

then be reused, or recycled, in an asphalt pavement project on the same roadway or another roadway. This reclaimed material can be recycled in a central plant or used as is on unimproved surfaces like gravel roads and storage lots. A brief description of these processes follows:

a. Heater planers have been around since the 1930's. It involves heating the pavement surface and planing the material off. Figure 1 illustrates a single unit and multiple unit processes.

b. Hot milling alone is rarely used in this country. Although, the process is often used in hot in-place recycling operations which will be discussed later.

c. Cold planing is usually performed in the summer to take advantage of the heat in order to make it easier to remove the material. The equipment used for this process is usually a motor grader.

d. Cold milling is a recent technology which uses high speed rotating teeth to remove the material. The process requires only one machine, called a milling machine, which is shown in Figure 2. This process is highly productive and economical. Some milling machines are capable of milling widths of up to 12 feet and depths of 6 inches in a single pass. Several passes of 2 to 3 inches are usually performed, for depths of 4 inches or more, to reduce machine wear. Depth accuracies within 1/8 inch can be achieved. The reclaimed material ranges up to about 1 inch in size, so further crushing of the material is generally not necessary. This reclaimed material can be placed in windrows on the

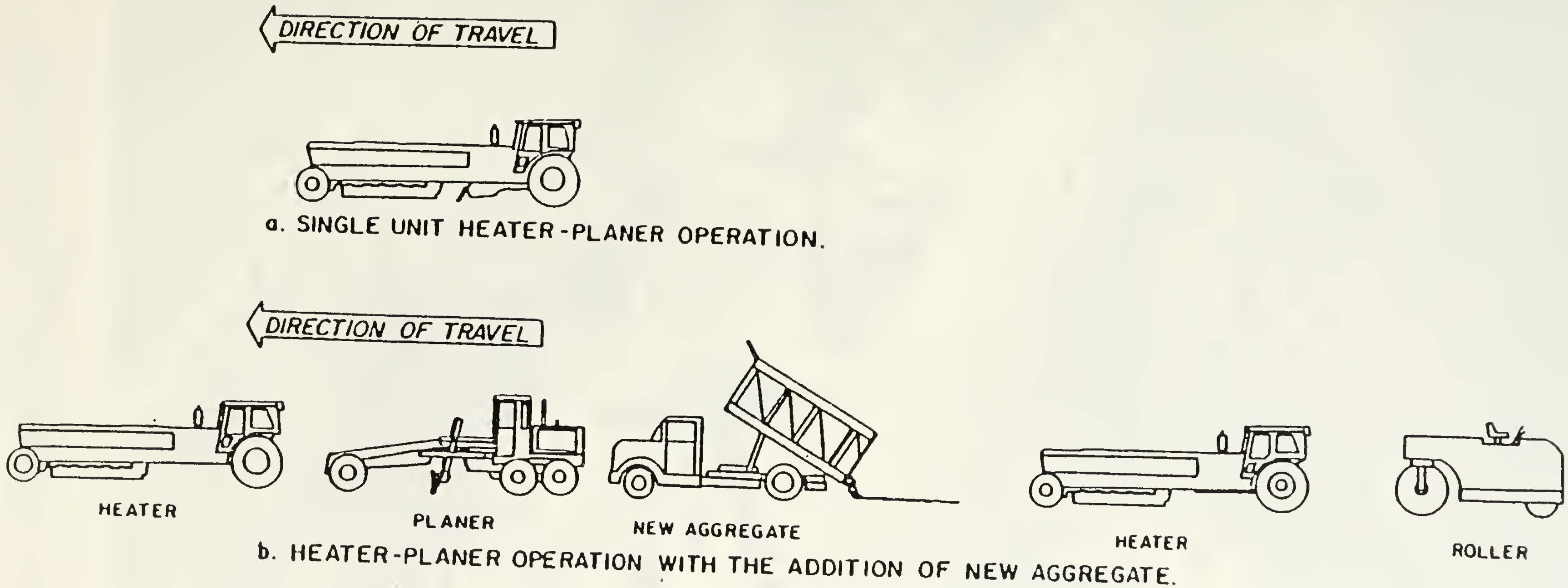


Figure 1. Heater Planer Operations
(From Epps, et al, 1980)

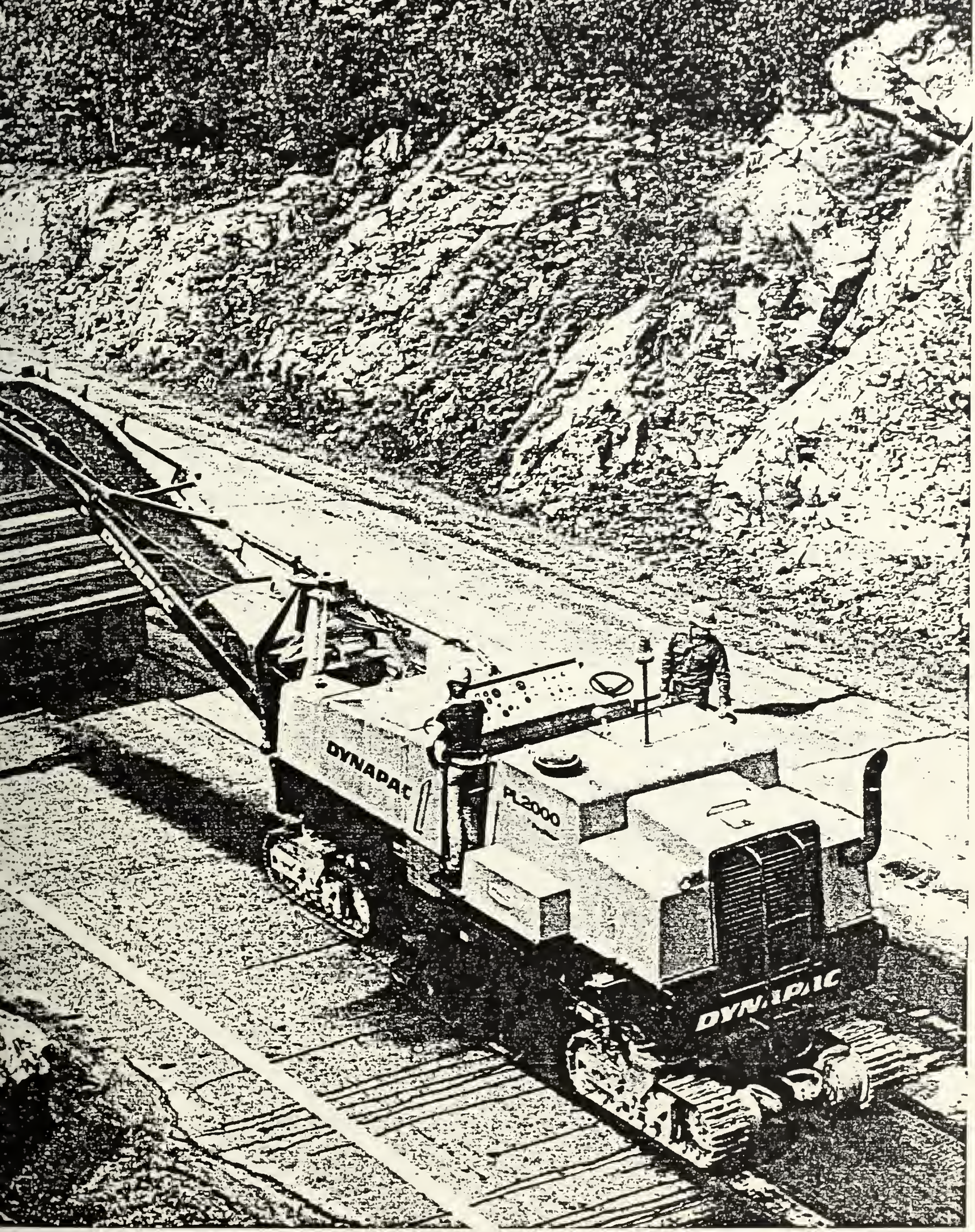


Figure 2. Pavement Milling Operation
(From Dynapac Advertisement Brochure)

roadway or in dump trucks as the milling machine is traveling the project roadway. Weather has little affect on the operation. However, milling does tend to create an excessive amount of fines for some uses. The constant pounding against the road surface can create tremendous tooth wear. Since milling machines have between 170 and 500 teeth, downtime for replacement can be time consuming and expensive.

3. Surface Reworking Processes

Heater scarification and hot in-place recycling processes are two surface reworking processes. As discussed earlier, hot in-place recycling is considered an in-place recycling process and will be discussed under 'In-Place Recycling.'

Unlike the surface removal processes discussed previously, heater scarification is a true recycling operation. This process heats and scarifies the asphalt pavement surface. New materials and/or a modifier are added to the loosened surface material as required to correct surface distress problems. The materials are then screeded by a laydown machine and compacted. Compaction is accomplished by steel drum and rubber tired rollers. Three illustrations of this process are shown in Figure 3.

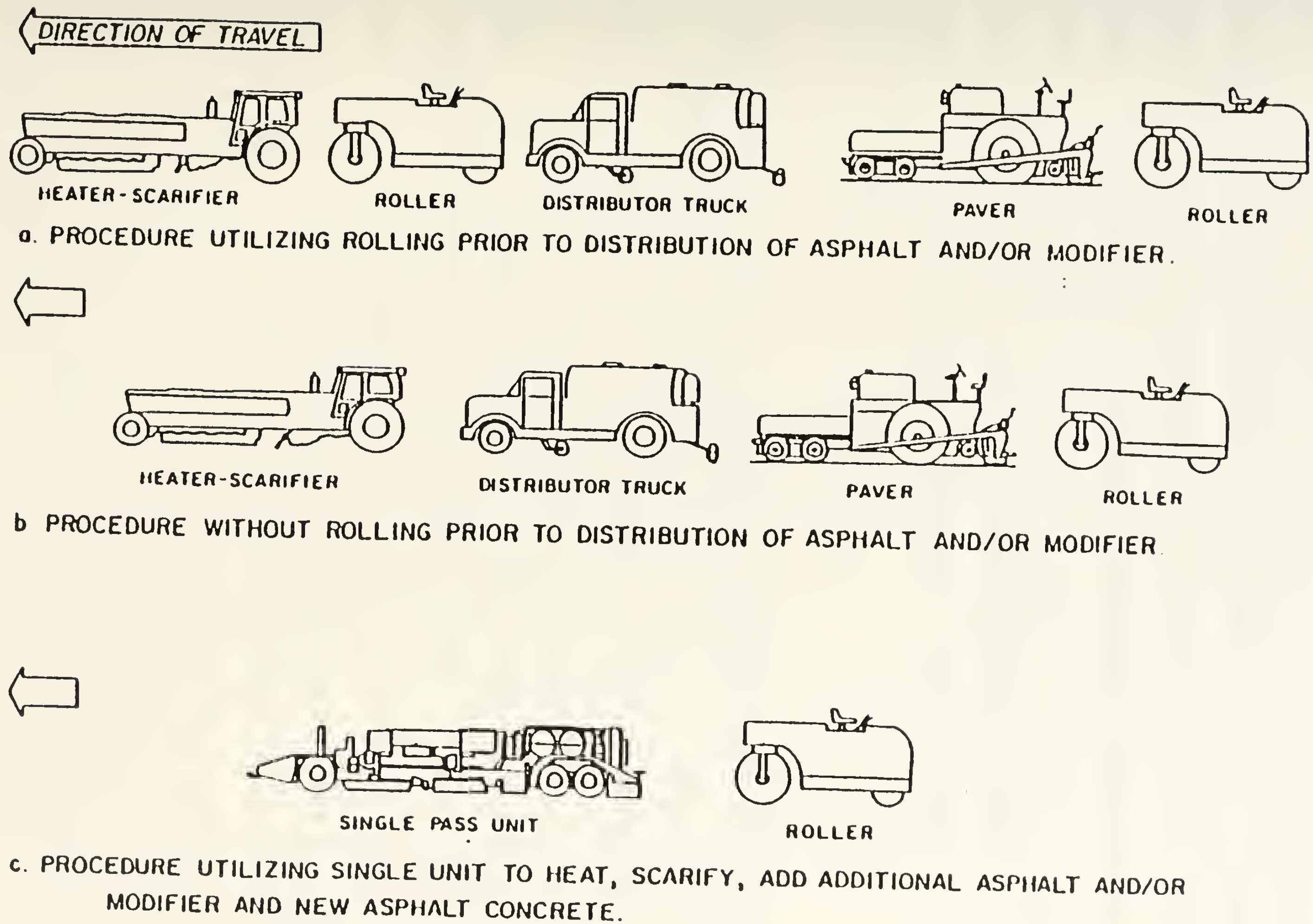


Figure 3. Heater Scarification Operations
(From Epps, et al, 1980)

This process is used to correct distresses in asphalt pavement surfaces like cracks, distortions, disintegrations, and skid hazards. It is also used prior to overlays to correct pavement distresses and provide better bonding between the existing pavement and the overlay. Roadways recycled by heater scarification are often seal coated or overlayed with new hot mix to seal the recycled pavement and provide a more durable wearing surface. This process is normally used on low to high volume roadways depending upon the type of surface treatment applied. High volume roadways would require hot mix overlays.

The effectiveness and efficiency of heater scarification is highly affected by weather conditions. Wind and cool temperatures can drastically reduce effectiveness of the heaters. Rain will also cool the heated pavement surface and penetrate the loosened material. This requires that heater scarification operations shut down during rainy conditions. Moisture in the pavement from previous rains will also greatly affect the efficiency of the operation. These conditions not only decrease the efficiency by requiring a greater heating effort, but also tend to slow, or stop, the entire process resulting in lower productivity. High heat loss conditions require immediate rolling of the surface to obtain proper compaction.

Some environmental disadvantages are air pollution and scorching. Heater scarification operations can be tremendous polluters and scorch roadside vegetation. These negative side effects have resulted in equipment modifications, but the process is still restricted in some parts of the country.

Quality control is another problem. The depth of scarification is not always consistent. Maintaining proper speed and temperature are frequent problems. These problems result in poor quality and efficiency.

C. Central Plant Recycling

1. General

Central plant recycling is defined as the "removal of the pavement from the roadway after or prior to pulverization, processing of material with or without the addition of a modifier, followed by laydown and compaction to the designed grade and depth" (Finn, 1980). The material is hauled to a central plant for processing. This can be a cold or hot process. The asphalt pavement material is removed from the roadway by surface removal processes or dozers with rippers.

The surface removal processes such as hot and cold milling, cold planing, and heater planing were described earlier in the'Surface Recycling' section. Cold milling is the most popular technique. It is very effective for use in removing pavement material to be hauled to a central plant.

The use of dozers with rippers is the traditional approach. This technique requires crushing of the pavement rubble and sizing at a crushing plant. This usually costs slightly more than other surface removal techniques like milling, but it is still popular with many contractors and some agencies. Contractors use the dozer technique since they usually have this type of equipment in their possession. The specialized pavement milling processes are usually subcontracted. Some agencies prefer the dozer technique since it generally produces fewer fines than milling.

2. Hot Process

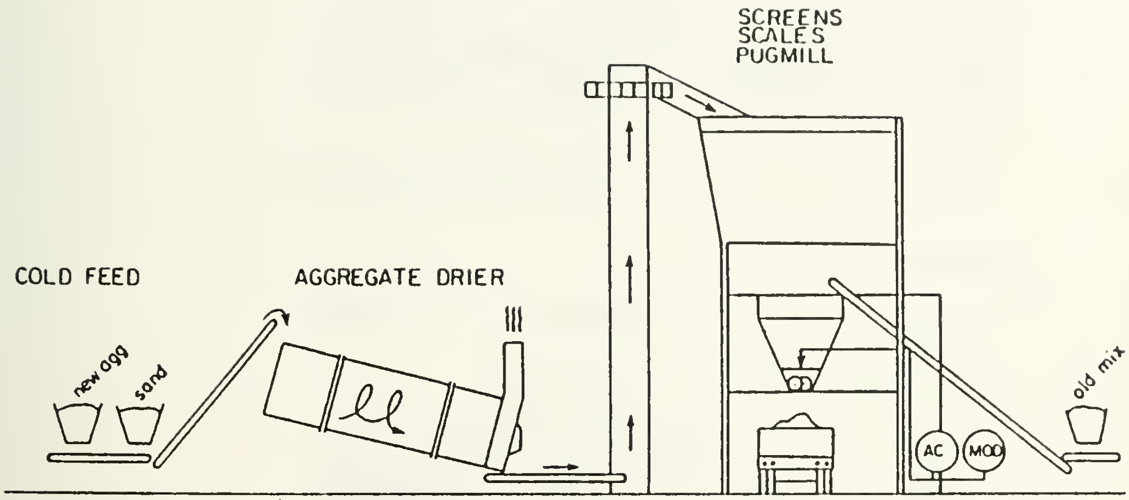
Hot mix recycling in a central plant has been a very popular process since the mid 1970's. It is probably the single most specified and used recycling process in use today. Many agencies allow this process by specifying a maximum percent of reclaimed material that can be mixed with the new hot mix material for an asphalt pavement project. It is usually the most expensive and intensive recycling process.

The asphalt pavement removed from the roadway is mixed with new aggregates, new asphalt, and/or modifiers in a hot plant operation. This process forms a hot mix resembling a new hot mix in appearance and properties. The combined material is hauled back to the roadway, placed by a laydown machine, and compacted. Steel drum and rubber tired rollers compact the pavement material in the same way as a conventional asphalt overlay.

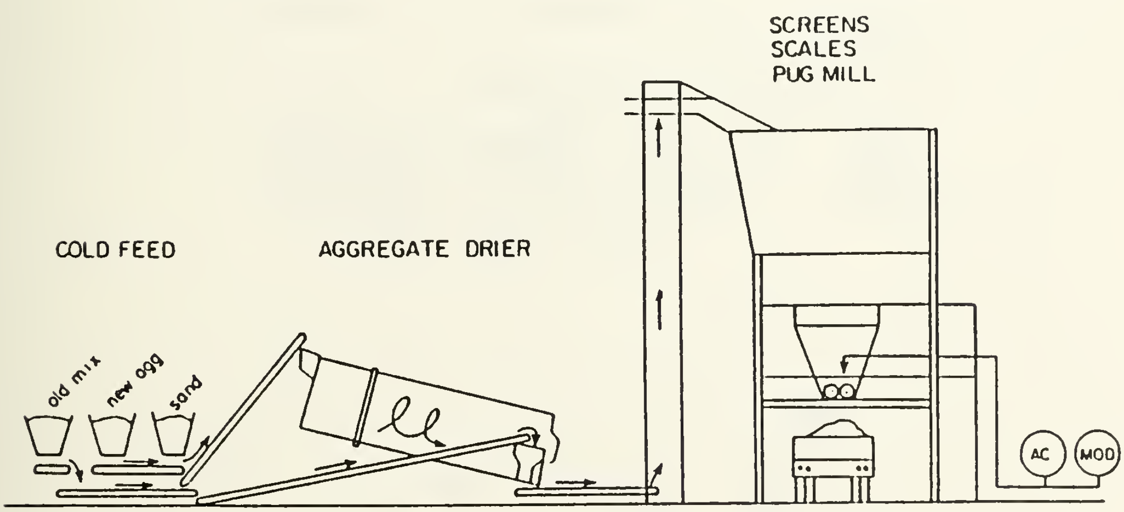
When interest in central plant hot mix recycling picked up in the mid 1970's, most hot mix plants were standard batch plants with pug mills. This technique screens aggregates by size into bins which feed the sized aggregates into a dryer drum. The dryer drum dries and superheats the aggregates. The aggregates are then fed through screens into bins which weigh out the proper proportion of each size of aggregate into a pug mill. As the heated aggregates are mixed together, asphalt is introduced and mixed with the aggregates forming a homogenous batch of hot mix.

Hot mix recycled pavement material can be produced by standard batch plants, with modifications, as shown in Figure 4 (Epps, et al, 1980). The reclaimed material is combined with the new aggregates at the end of the drum drier or in the pug mill. Standard batch plants are mainly used for conventional hot mix production, since the drum mixer process is better designed to handle reclaimed asphalt pavement materials.

Central plant hot mix recycling did not become very popular until the drum mixer process was developed. The drum mixer process is designed to prevent the burner flame that dries the new aggregates from coming into direct contact with the reclaimed asphalt pavement materials. The superheated aggregates are used to heat the reclaimed materials. This



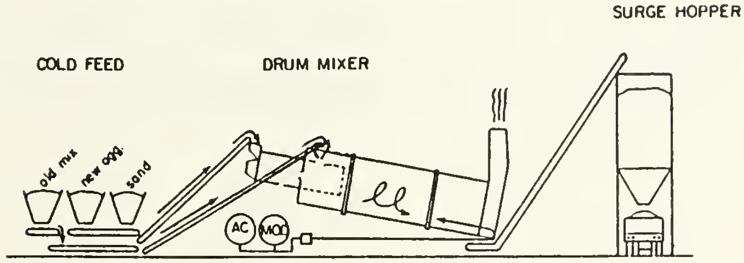
a. Old Mix Added At Pug Mill



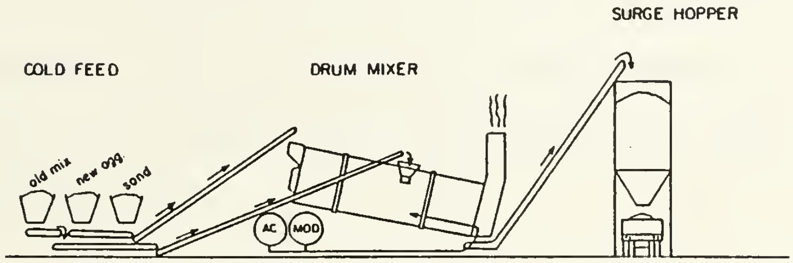
b. Old Mix Added At Drier Discharge

Figure 4. Standard Batch Plants Set Up
For Hot Recycling
(From Epps, et al, 1980)

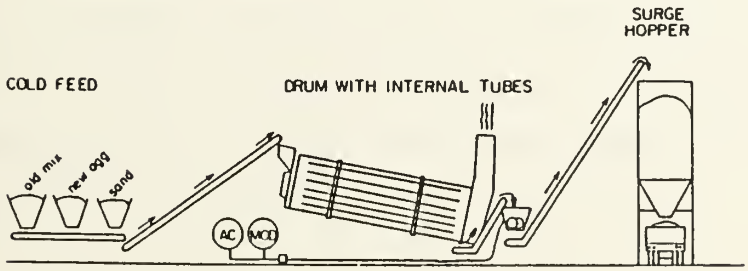
a. Flame Diffuser Method



b. Drum-Within-A-Drum Method



c. Dual Feed Method



d. Indirect Heating Method

Figure 5. Types Of Drum Mixer Plants
(From Epps, et al, 1980)

technique minimizes air pollution and destruction of the reclaimed asphalt binder. The new aggregates are sized into bins and fed into the drum mixer according to proper design proportions. The drum mixer dries and superheats the new aggregate. The heated aggregates are mixed with reclaimed asphalt pavement material downstream within the drum mixer. New asphalt and/or modifiers are added to the combined material from the rear of the drum mixer. The material leaving the drum drier is a homogenous asphalt mixture of new and old materials.

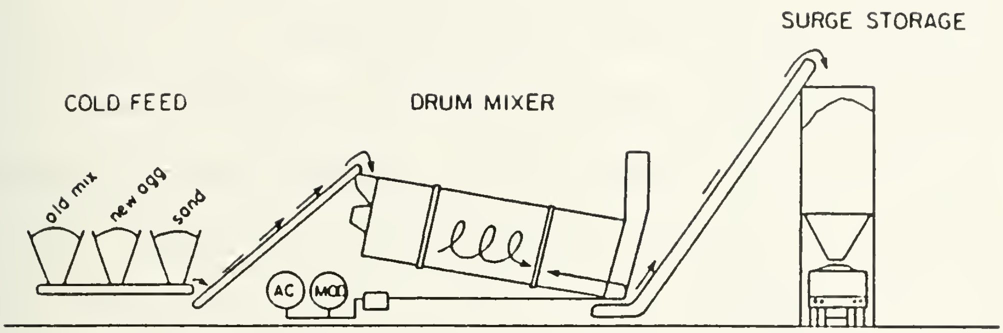
The drum mixer process has higher production and energy efficiency compared with the standard batch plant. Drum mixer plants are also capable or producing conventional hot mix. Many contractors are switching to these plants so that they can produce conventional and recycled hot mix efficiently and effectively.

There are several methods of drum mixing plant operations set up for hot mix recycling. Some examples of these are the Flame Diffuser Method, Drum Within A Drum Method, Dual Feed Method, and Indirect Heating Method which are shown in Figure 5 (Epps, et al, 1980). The most popular is the Dual Feed Method.

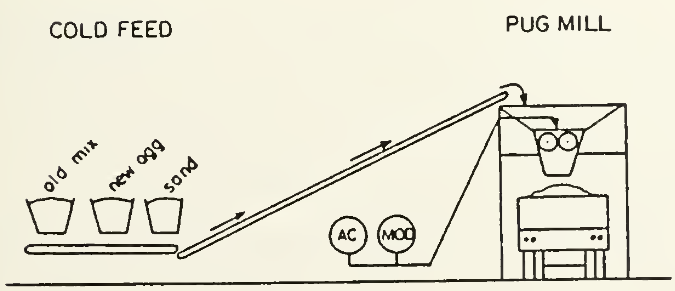
3. Cold Process

Cold central plant recycling utilizes the same types of central plant as used for producing conventional and recycled hot mix. The operation is very similar to the hot process, but as the name implies there is not heat. The asphalt pavement material removed from the roadway can be fed into a drum mixer or a conventional batch plant as shown in Figure 6 (Epps, et al, 1980). The reclaimed material is mixed with new aggregates, asphalt and/or modifiers in the plant. The modifiers and new asphalts may or may not be heated depending on the type of modifier and asphalt used. If heated, it would only be for means of dispensing. The modifier and new asphalt rejuvenate the old asphalt binder to make it more workable and restore its properties to the equivalent of asphalts used in new mixtures. The mixed material is then hauled back to the roadway, placed by a laydown machine, and compacted. Compaction is performed with steel drum and rubber tired rollers the same way a conventional hot mix pavement would be.

The cold central plant process is best suited for low volume roadways. A finish course, usually a seal coat, is placed on the recycled pavement surface for protection from weather and to improve skid resistance.



a. Drum Mixer Used To Produce Cold Recycled Mix



b. Standard Batch Plant Used To
Produce Cold Recycled Mix

Figure 6. Central Plants Set Up
For Cold Recycling
(From Epps, ét al, 1980)

D. In-Place Recycling

1. General

The definition of in-place recycling is "in-place pulverization to a depth greater than 1 inch followed by reshaping and compaction" (Finn, 1980). The recycling work is performed on the roadway and no central plant is involved, except for supplying any new mix to be used on the project. In-place recycling can be a cold or hot process. It usually requires the addition of new aggregates, asphalt, asphalt mix, and/or modifiers. The hot in-place process is generally used for recycling portions of or the entire depth of an asphalt pavement up to a maximum of about 2 inches. The cold process is usually used to recycle the entire pavement depth and part of the base material. In the past, most people associated in-place recycling as a cold in-place process.

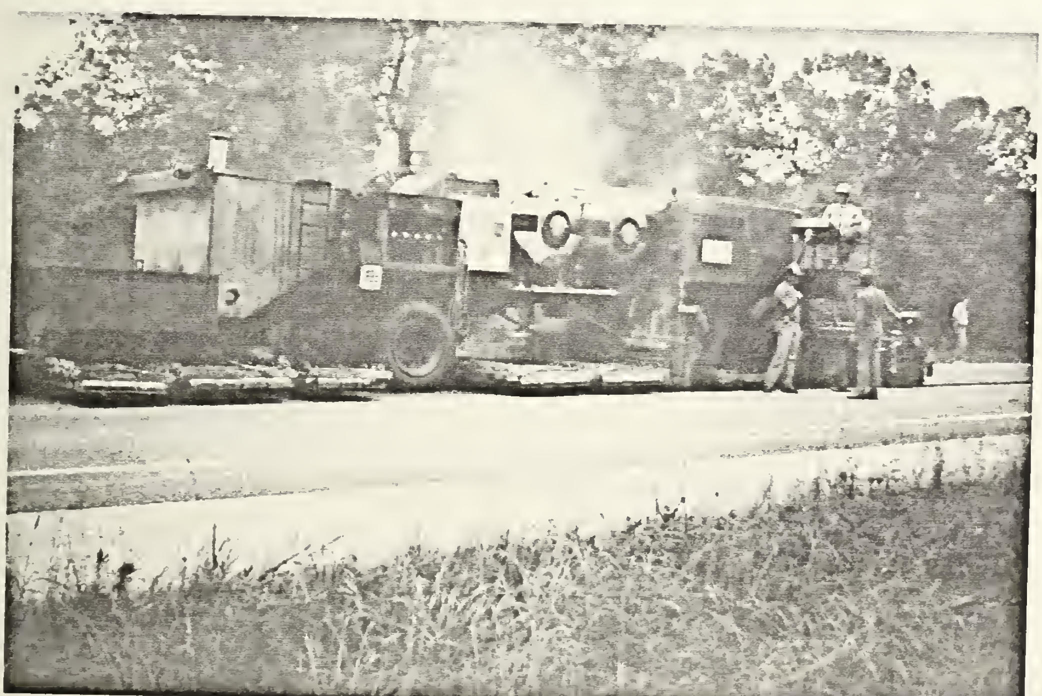
2. Hot Process

Hot in-place recycling is a relatively new field of recycling operations. This process has been categorized as surface, hot in-place, and surface in-place recycling. While there is still some debate within the asphalt pavement recycling industry as to the appropriate category to use, most agree that it is an in-place process even though it can perform surface recycling techniques. Many within the industry feel that it should not be categorized under surface recycling for two reasons: (1) negative connotations associated with surface recycling from past failures, and (2) it is capable of recycling much more than just the top 1 inch of pavement.

The process involves heating the pavement surface with mobile heaters to soften the pavement. The pavement is loosened by means of scarification and/or hot milling. New aggregate, asphalt, hot mix, and/or modifiers is usually added to correct pavement distress. The new materials are then mixed in-place with the existing loosened surface material. The combined materials are screeded and compacted. Steel drum and rubber tired rollers are used for compaction. Most of these processes are capable of mixing the new hot mix with the existing surface material, or placing it as an overlay on the surface of the screeded recycled material. The third procedure (item C) of Figure 3 is an illustration of this process. Figure 7 shows the Cutler and Wirtgen processes respectively in operation.

The equipment involved is usually one or two preheating units and the recycling unit. This recycling unit is not a standard specification type of machine. Each firm that designs and manufactures these machines has a slightly different philosophy concerning recycling of asphalt pavements. So, each firm produces their own unique machine. Since the area of hot in-place recycling is relatively new, most of these firms are using their experience and new technologies to improve their process. Some firms have two, three, or more generations of their own equipment. The types of preheaters vary also, but most are essentially the same. Several of these processes are discussed in more detail in a later section titled "Evaluation Of Various Processes."

a. Cutler Repaver



b. Wirtgen Repaver/Remixer

Figure 7. Typical Hot In-Place Recycling Operations

There are many advantages in using these types of processes. Their designs make it possible to correct almost any type of pavement distress. However, the roadway structure should be in good condition. Rehabilitation of a roadway distress caused by structural problems will result in recurring distress. The operation of the equipment is versatile, yet highly automated. Operational capabilities such as adjustable widths, speeds, temperatures, and depths, and the addition of different types and amounts of new materials make these machines very flexible to meet the project requirements.

Some disadvantages like weather conditions, environment, and lack of standardized equipment can create problems. The same weather problems and, to a lesser degree, the same environmental problems associated with heater scarification are also problems with hot in-place recycling. Non-standardized equipment can make it difficult to specify a particular technique without writing proprietary specifications.

3. Cold Process

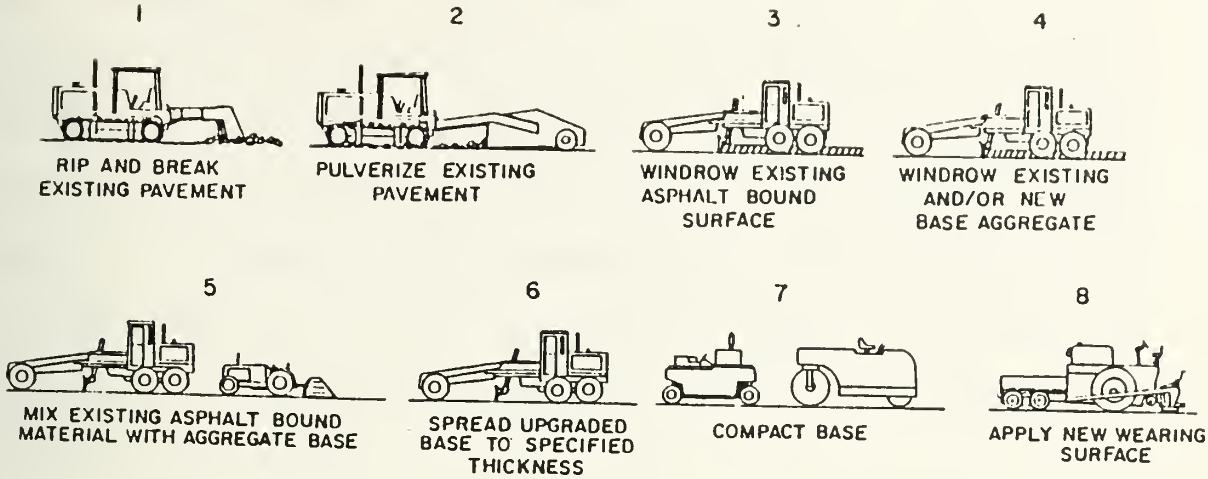
The cold in-place recycling process usually involves recycling the entire asphalt pavement. The existing base material can also be recycled with the asphalt pavement. The pavement is broken up by ripping and is pulverized by a pulverizer on the roadway. If the pavement is less than 6 inches, ripping is usually not necessary. This process is

illustrated in Figure 8. A milling machine may also be used to remove the pavement material leaving it on the roadway in a windrow. Steps 1 and 2 of the illustrations could be replaced by a milling machine, if the milling technique is used. The removed pavement material is windrowed and new materials and a modifier, if required, are mixed in with the old pavement material by a motor grader. The combined materials are spread across the roadway and compacted. Compaction is performed with steel drum and rubber tired rollers.

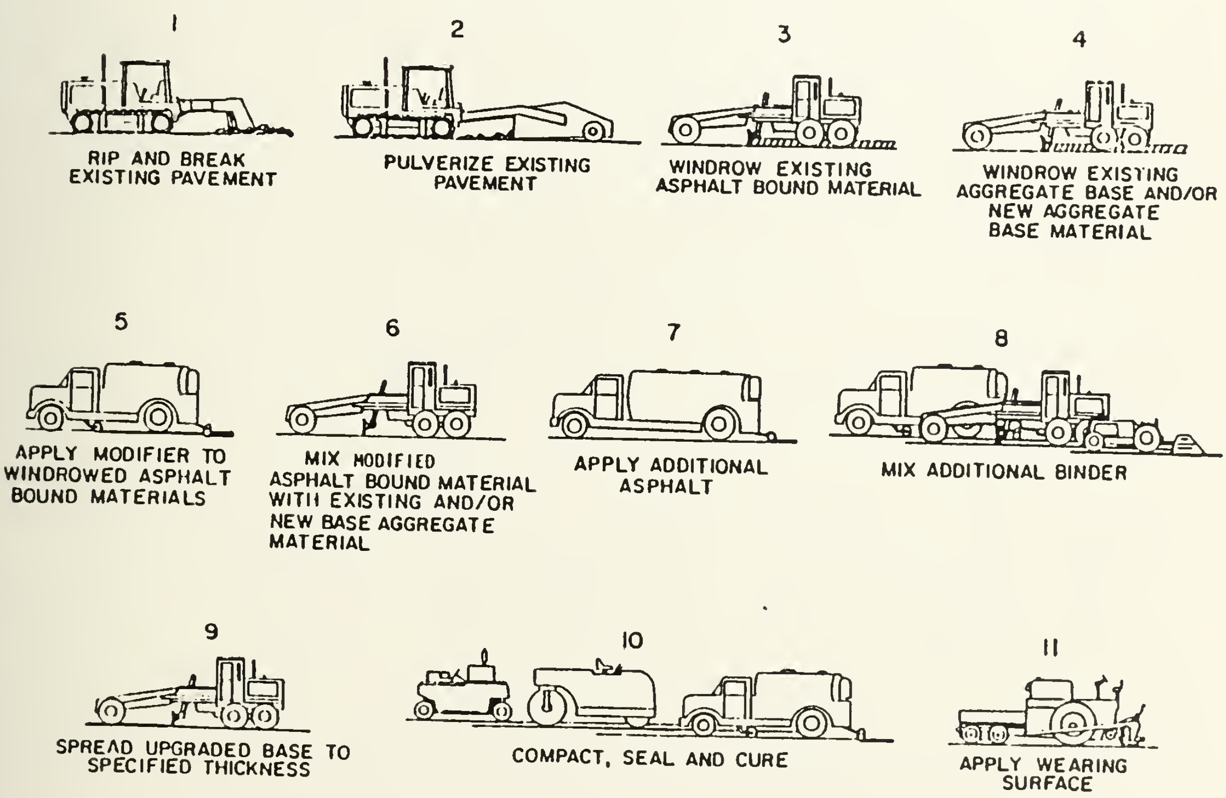
The most frequent problems encountered by this process are inefficient mixing, weather, and non-standardized equipment. The nature of mixing on the roadway with a motor grader makes it difficult to achieve a homogenous mix of all the materials. This is especially true, if the motor grader operator is inexperienced.

Weather can not be controlled, so it is an important item to monitor. Cold and/or wet weather conditions cause mixing, spreading, and compaction problems. Cold in-place recycling operations should cease during foggy or rainy weather or when the temperature drops below 50 degrees Fahrenheit (degrees).

The types of equipment used in cold in-place recycling are not standardized. The Asphalt Recycling and Reclaiming Association is working to develop specifications for a new machine that would be a self-propelled pulverizer.



a. Without Restabilizer



b. With New Aggregate, Modifier, And Asphalt

Figure 8. Typical Cold In-Place Recycling Operations (From Epps, et al, 1980)

Cold in-place recycling is usually used on low volume roadways. The surface of the recycled pavement is usually covered by a seal coat or new hot mix wearing surface. This method produces an improved base material for a more durable roadway. Since many of our roadways are not designed for the type and amount of traffic they serve today, cold in-place recycling is an effective and economical alternative for roadway reconstruction.

IV. TYPES OF PAVEMENT DISTRESS

A. General

The types of pavement distress most common to asphalt pavements are listed and discussed herein to provide information about what distress is and what causes it. Once we understand this and the capabilities of the various pavement rehabilitation methods, the proper method can be chosen for each particular situation to obtain the best results. Thus, it is essential to know the types and causes of distress.

Pavement distress is evidence of some type of roadway deterioration. If left untreated, the pavement will eventually disintegrate. Most types of distress grow worse with the passing of time and continued traffic flow upon a weakened pavement. It is more economical to repair a distressed roadway in its early stages of failure before more damage is done resulting in greater repair cost.

The repair discussions herein are not intended to identify the various methods of repair for each type of distress, nor, do they suggest the best recycling method. The focus of this report deals with hot in-place recycling, so the repair methods discussed will be restricted to this process. It is not the intent of this section to suggest that hot in-place recycling is the best method to deal with each type of distress. Rather, each pavement must be evaluated on a case by case basis for selecting the best method of repair for the

type of deterioration present, be it conventional or recycling. The extent of distress will dictate the most economical method. The 'Project Selection and Design Considerations' section will discuss items to be considered when choosing a method of rehabilitation.

B. Cracking

1. General

Cracking, the most prevalent type of asphalt pavement distress, appears in many forms. Cracks are areas of movement within the pavement resulting from any number of causes as discussed hereafter under each category.

2. Alligator Cracks

Alligator, or fatigue, cracks "are interconnected cracks forming aseries of small blocks resembling an alligator's skin or chicken-wire" (MS-16, 1977) as shown in Figure 9.

The causes of alligator cracking are: structural deficiency, excess air voids in the asphalt pavement, change in asphalt properties, asphalt stripping from the aggregate, poor aggregate gradation, poor drainage, and improper construction. The most frequent cause of alligator cracking is excessive deflection of the pavement surface because of unstable, lower pavement layers in the roadway structure. The unstable condition is usually a result of moisture infiltrating the roadway and saturating the base and/or subgrade layers. This usually only affects a small area.

Figure 9. Alligator Cracks

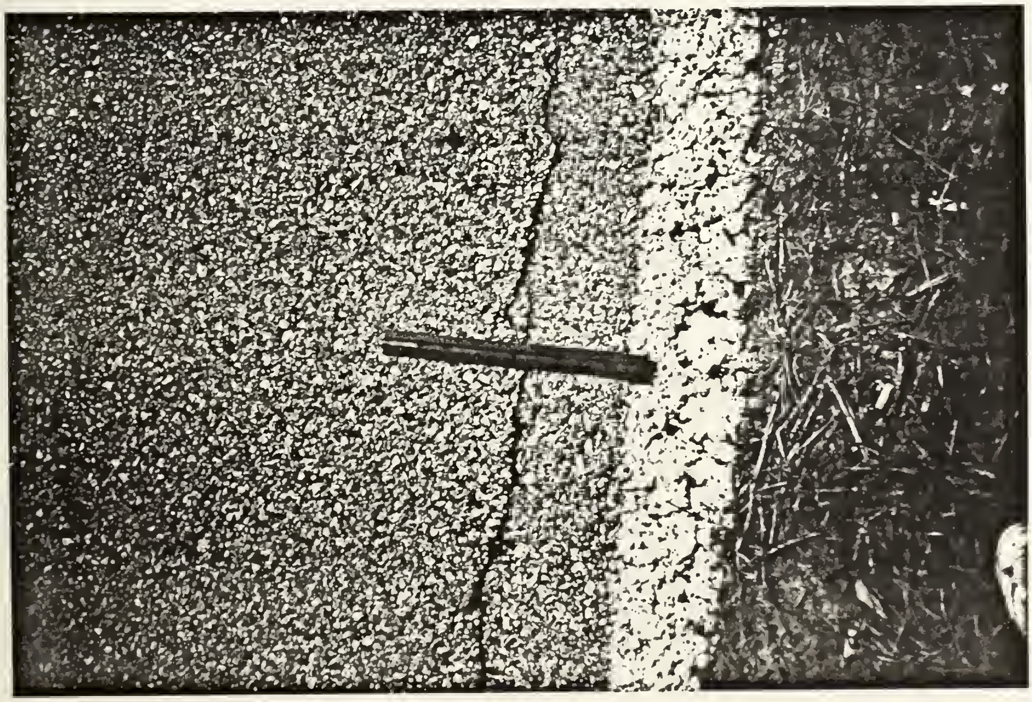


Figure 10. Edge Cracks

However, it can occur over an entire section of pavement as a result of improper drainage design. Repeated loads exceeding the load capacity of the pavement will also cause alligator cracking over large sections of pavement.

Repairing cracks resulting from a moisture saturated roadway structure, requires that the moisture problem be corrected first. Then if needed, hot in-place recycling can correct the surface problems. If the cracks resulted from repeated loads exceeding the pavement load capacity, hot in-place recycling can be used to correct the cracks. Cracks resulting from excess loads, will require the addition of new hot mix as an overlay on top of the recycled surface, or mixed with the reclaimed pavement material. The additional mix is used to make a stronger and more durable pavement by increasing its thickness, and to retard cracks from recurring.

3. Longitudinal Cracks

a. General

There are several types of longitudinal cracks: edge, edge joint, and lane joint as discussed by the Asphalt Institute, Manual Series No. 16. Longitudinal cracks are sometimes the first indication of developing alligator cracks. In which case the causes would be the same as with alligator cracks. Other causes are: aggregate segregation, shrinkage, and settlement or volume changes in the underlying courses.

b. Edge Cracks

"These are longitudinal cracks a third of a meter (one foot) or so from the edge of the pavement with or without transverse cracks branching towards the shoulder" (MS-16, 1977) as shown in Figure 10. They can occur in small or large sections.

Edge cracks are a result of inadequate lateral support from the shoulder of the roadway, settlement, or yielding of underlying material. The later two may be due to improper drainage or frost heave. Heavy vegetation near the pavement edge can extract moisture out of the surrounding soil causing shrinkage which results in inadequate lateral support for the roadway.

The structural problems must be corrected first. Hot in-place recycling should be used to correct the cracking and restore the pavement surface, only after the structural problems have been corrected.

c. Edge Joint Cracks

"An edge joint crack is really a seam. It is the separation of the joint between the pavement and the shoulder" (M-16, 1977).

Causes of edge joint cracks are mix shrinkage, ponding water, shoulder settlement, and straddling. Vehicles straddling a shoulder joint, either stationary or moving, tend to

encourage such failures due to inadequate compaction on the shoulder or lack of lateral support for the shoulder. A higher shoulder, raised joint filler, depressions, or grass ridges in a shoulder joint tend to hold water allowing it to seep into the joint before it can evaporated off of the roadway.

In order to correct this type of distress, the drainage and structural problems must be corrected first. Then, hot in-place recycling can correct the surface problems. However, hot in-place recycling may not be the best solution for a single edge crack.

d. Lane Joint Cracks

The Asphalt Institute defines lane joint cracks as "longitudinal separations along the seam between two paving lanes" (MS-16, 1977) as shown in Figure 11. These are usually caused as a result of a weak seam in an adjoining pavement course or by 'cold joint' construction. Cold joint is a weak bond that occurs when a fresh hot mix course is placed adjacent to a hot mix course that has cooled. Such cracks allow moisture to migrate through and under a pavement surface. Hot in-place recycling would probably not be very efficient to use due to the small area, but could correct the surface problem.

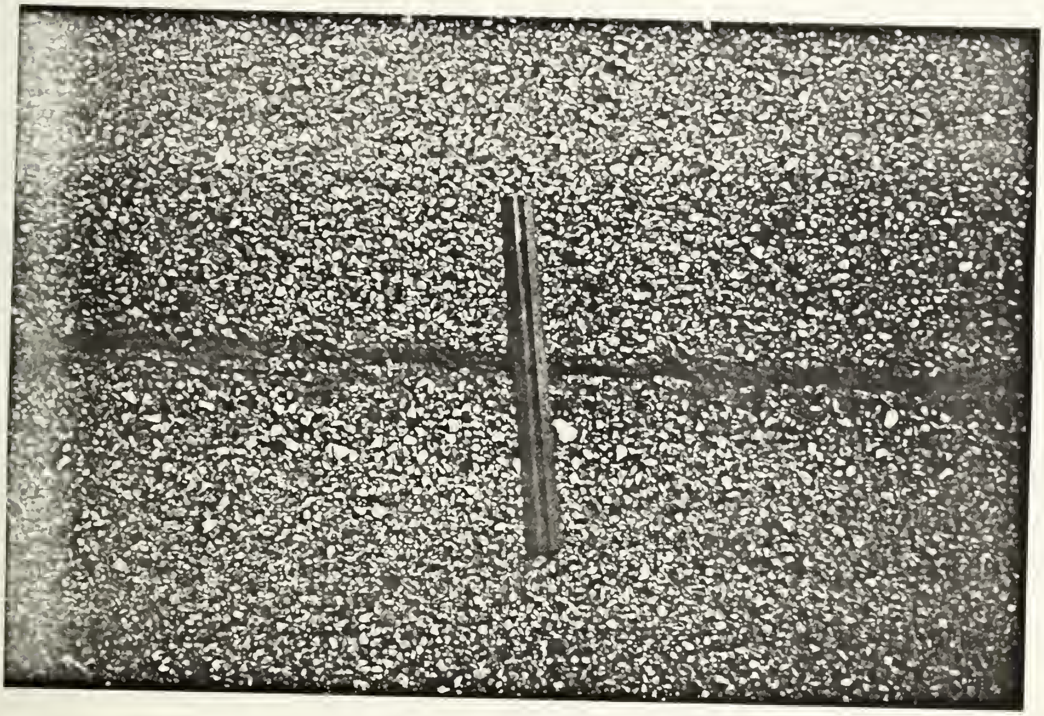


Figure 11. Lane Joint Cracks

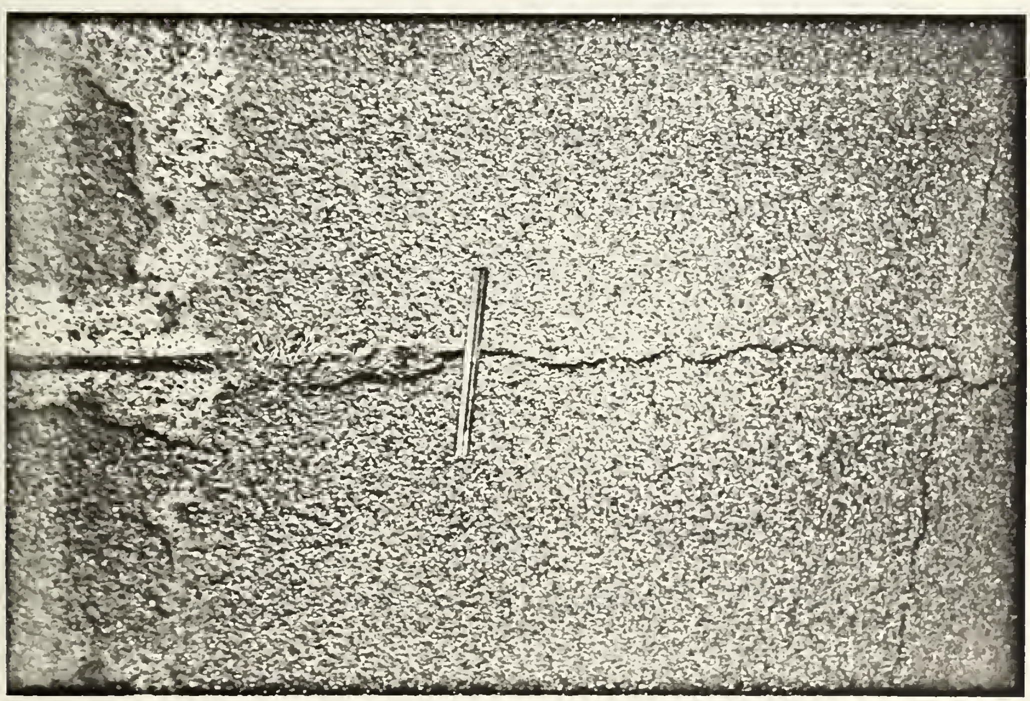


Figure 12. Reflective Cracks

4. Reflection Cracks

"These are cracks in asphalt overlays which reflect the crack pattern in the pavement structure underneath .... The pattern may be longitudinal, transverse, diagonal, or block" (MS-16, 1977). Figure 12 shows an example of reflection cracks. These are usually a reflection of cracks or joints in underlying asphalt pavements, portland cement concrete pavements, or cement-treated bases. Horizontal and vertical movements at the cracks or joints in the underlying structure cause cracks to migrate up through the asphalt pavement overlay at the same location. This movement can be caused by earth movements, moisture or temperature changes, traffic, or more likely a combination of these.

Reflective cracking is hard to stop. Fixing the problem, which is usually deep within the pavement structure, usually requires ripping the pavement up to rework the cracked base or repair the underlying pavement cracks and joints. Hot in-place recycling can restore the pavement surface, but the cracks will eventually reappear.

5. Shrinkage Cracks

Shrinkage cracks as defined by the Asphalt Institute "are interconnected cracks forming a series of large blocks, usually with sharp corners or angles" (MS-16, 1977) as in Figure 13.

These are caused by volume changes in the asphalt pavement mix, base, or subgrades. Fine aggregate asphalt mixes with large percentage of low penetration asphalt cement are especially prone to these volume changes. Low traffic volumes tend to increase this type of cracking in such pavements.

Hot in-place recycling can restore this type of pavement cracking resulting from volume changes in the asphalt pavement. One theory suggest that recycling a pavement that has experienced shrinkage cracks would eliminate or reduce the number of such cracks in the recycled mix, as the asphalt has already equalized. This has neither been proven a fact, nor totally disproved. Bases and subgrades that continue to experience volume changes are not good candidates for hot in-place recycling as such cracks will recur through the recycled pavement.

C. Distortions

1. General

"Pavement distortion is any change of the pavement surface from its original shape," (MS-16, 1977) such as ruts, corrugations, shoving, depressions, and upheavals. Distortions are the result of a number of problems including: poor compaction of a pavement or underlying courses, swelling of underlying courses, too much asphalt, too many fines in the pavement course, or settlement of the roadway.

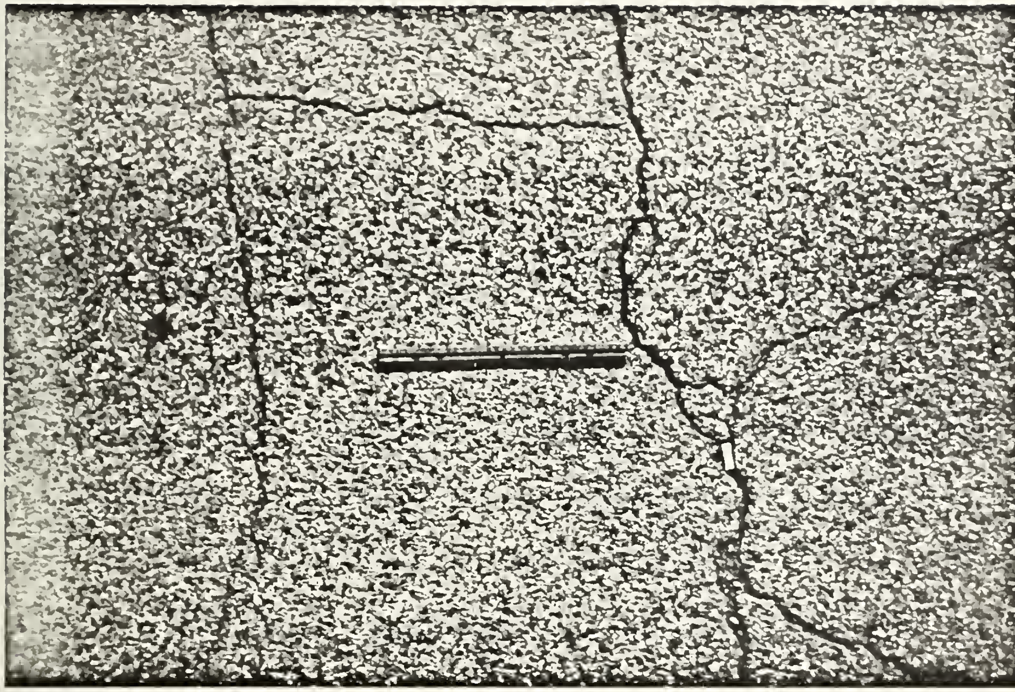


Figure 13. Shrinkage Cracks

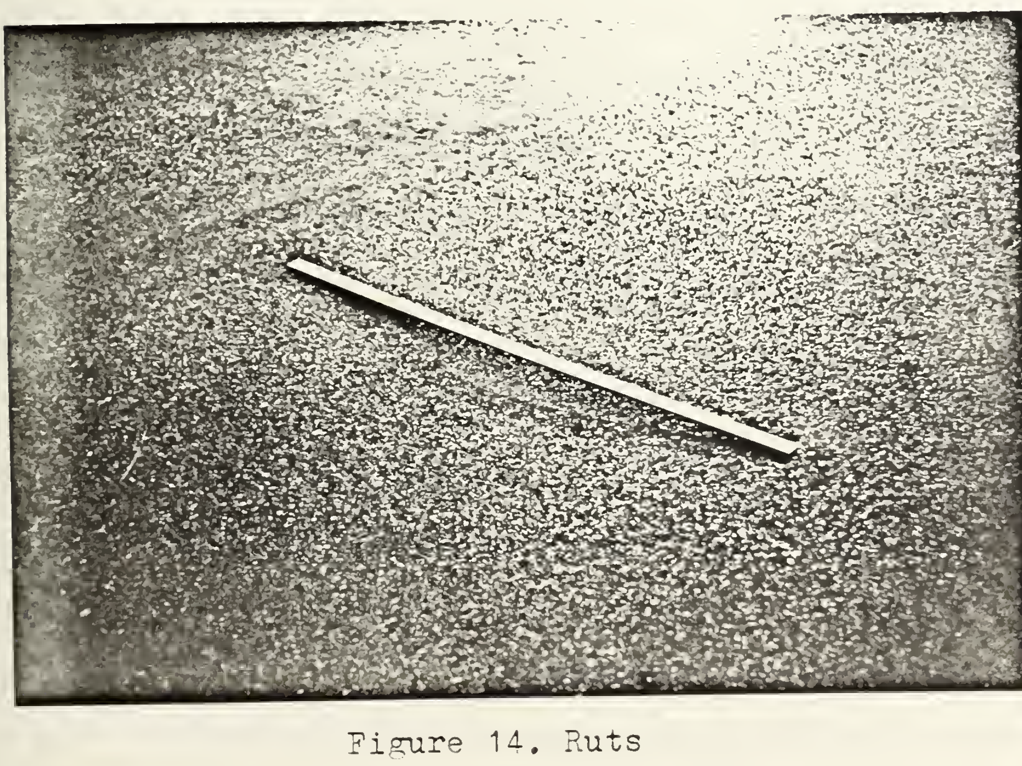


Figure 14. Ruts

2. Ruts

Ruts are sometimes called channels. They are "channelized depressions which may develop in the wheel tracks of an asphalt pavement" (MS-16, 1977) as shown in Figure 14. Ruts are caused by consolidation or lateral movement of a pavement or underlying courses brought on by traffic. If proper compaction is not obtained during construction of an asphalt pavement, then traffic loads are likely to consolidate the pavement mix along the wheel paths. Plastic instability within a pavement mix may also produce the same effect under traffic. In colder climates where studded tires are used, pavements with soft aggregates can be worn or raveled forming ruts.

Repairing ruts by hot in-place recycling is very common. However, two inch deep ruts will not be corrected by recycling the top inch of pavement. Hot in-place recycling can include an admixture designed to help stabilize an unstable mix. Mixing the old pavement with a mix containing a lower asphalt content, 'dry mix,' can correct a plastic movement situation.

3. Corrugations and Shoving

The Asphalt Institute lumps these conditions together as they are very similar in occurence and methods of rehabilitation. Corrugations, often called 'washboarding' or 'rippling', are defined as "a form of plastic movement typified by ripples across the asphalt pavement surface .... Shoving is a form of

plastic movement resulting in localized bulging of the pavement surface..." (MS-16, 1977). See Figures 15 and 16 as examples of these respective conditions. Both conditions will be referred to as shoving hereafter. Shoving typically occurs on hills, curves, near bumps, and near intersections. These are areas where traffic speed and/or direction is changed in a relatively short distance. Pavements on curves and hills are subjected to more than just the predominate perpendicular forces as traffic passes over these areas. The asphalt pavement material is being pushed down hill on hilly sections and laterally to the outside on curved sections. Shoving also occurs where road bumps cause traffic to bounce up and down along the following section of pavement.

Shoving is caused by poor mix design, changes in the properties of a pavements' asphalt binder, structural problems with underlying courses, or asphalt binder stripping from the aggregate. A poor mix design usually results in an unstable mix causing shoving. Mixture instability results from too much or too soft of an asphalt, the ratio of fine aggregates to course aggregates is too high, or aggregate texture is too smooth or too round. Another leading cause is asphalt binder 'stripping' from the aggregate. Stripping is defined as "a displacement of asphalt film from the aggregate surface in the presence of water" (Haas, et al, 1983). Other causes are improper gradation for interaction of the aggregate within a mix or the wrong asphalt binder.

Figure 15. Corrugations

Figure 16. Shoving

Hot in-place recycling is feasible only if the problem is in the surface course. The depth of treatment should be equal or nearly equal to the thickness of the surface course that is unstable. If the surface course is 3 inches thick, and a hot in-place recycling operation only rehabilitates the top 1 inch, then the majority of the surface course has not been rehabilitated and is still unstable. The shoving will eventually return in such cases.

4. Depressions

Depressions are defined as "localized low areas of limited size which may or may not be accompanied by cracking, ... They dip several centimeters (an inch) or more below grade and water will collect on them" (MS-16, 1977). An example is shown in Figure 17. These depressions are often called 'birdbaths.' Depressions not only cause pavement deterioration, but also cause safety hazards for motorists when they are filled with water or ice.

Causes of depressions include settlement of pavement layers, traffic exceeding design capacity of pavement, or poor construction or repairs. Pavements sometimes settle due to settlement in the surrounding area, causing depressions in the roadway. Under designed roadways will develop depressions as a sign of weakness. Improper construction on a section of roadway during initial construction, subsequent repairs, or utility crossings often result in depressions.

Figure 17. Depressions

Figure 18. Upheaval

These problems can be corrected by hot in-place recycling. Although, corrections may be required within the roadway before the surface course can be repaired.

5. Upheaval

"Upheaval is the localized upward displacement of a pavement due to swelling of the subgrade or some portion of the pavement structure" (MS-16, 1977), as shown in Figure 18. Such distortion is usually a result of ice expanding or moisture swelling in lower courses of the roadway structure.

This type of distress is probably not suited for hot in-place recycling. Upheaval requires repairs within the pavement structure not just the asphalt surface course.

C. Disintegration

1. General

The Asphalt Institute defines disintegration as "the breaking up of pavement into small loose fragments." Examples are pot holes and raveling. Other types of distress discussed above may also be referred to as disintegration, but this report will follow the Asphalt Institutes classification.

2. Pot Holes

The "bowl-shaped holes of various sizes in the pavement resulting from localized disintegration" (MS-16, 1977) are called 'pot holes,' see Figure 19. Pot holes are the most infamous type of pavement distress among the general public.

Pot holes usually begin as cracks in the pavement as a result of weakness in the pavement. These weaknesses result from too little asphalt, too thin an asphalt pavement surface, too many or too few fines, or poor drainage. Movement between these blocks of pavement results in 'pumping' of the underlying base material. The base material becomes saturated and is pumped out causing pavement to fail due to lack of support. Pot holes are advancements of other distress problems mentioned earlier such as alligator cracks. Pot holes should be patched immediately, due to traffic hazards and potential for greater pavement problems if left open.

Hot in-place recycling can be used in this situation by mixing in new materials to correct the existing surface mix problems. However, extensive pot holes or pot holes penetrating the base material would not be suitable. The pot holes must be repaired prior to a hot in-place recycling operation.

3. Raveling

Raveling is the "progressive separation of aggregate particles in a pavement from the surface downward or from the edges inward" (MS-16, 1977). Figure 20 is an example of raveling. Raveling is simply erosion of the pavement surface. Initially fine aggregates come off, then larger and

Figure 19. Pot Holes

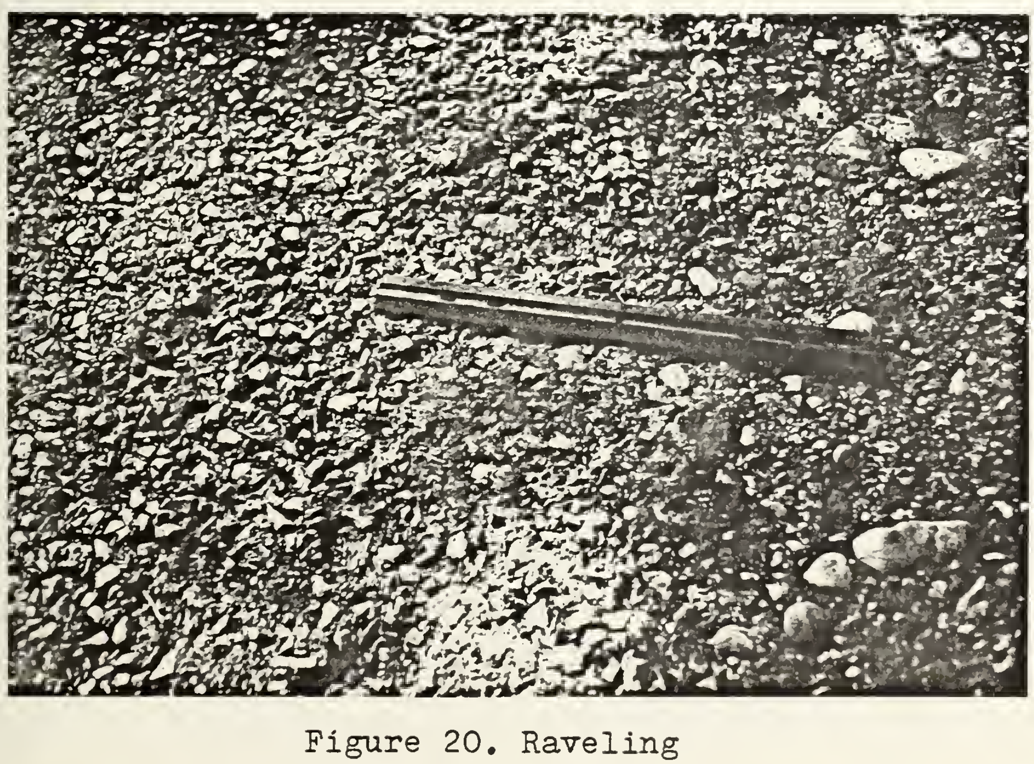


Figure 20. Raveling

larger aggregates are dislodged. This creates rough depressions allowing moisture and traffic to disintegration of the pavement.

Causes of raveling are poor compaction of the asphalt surface course when constructed, constructing the pavement in wet or cold weather, too little asphalt in mix, dirty or disintegrating aggregate in mix, overheated asphalt mix during construction, asphalt binder stripping from the aggregate, or a high voids ratio.

Hot in-place recycling is well suited to correct this type of problem. It can restore the existing asphalt pavement mix to its original, or near original, mix design by adding new materials.

D. Skid Hazards

1. General

Skid hazards are those pavement characteristics that prevent adequate traction on a wet pavement. Bleeding and polished aggregate are the two dominate examples. In order to improve traction and eliminate skidding hazards, the pavement surface must be restored such that water can flow around the surface aggregate, allowing the tire to contact the exposed aggregates.

2. Flushing

Flushing, commonly called 'bleeding,' is defined as the "upward movement of asphalt in an asphalt pavement resulting in the formation of a film of asphalt on the surface" (MS-16, 1977), as shown in Figure 21. The cause of bleeding is too much asphalt in the roadway. This condition is usually brought out in hot weather or heavy traffic. The hot weather makes the asphalt softer, allowing it to move to the surface. Heavy traffic can also force excess asphalt to the surface. The sources of this extra asphalt can be an existing hot mix, seal coat, or other road oils. Correction of a flushing condition by hot in-place recycling is quite effective. A dryer hot mix or new aggregate can be mixed in with the reclaimed material to lower the combined asphalt content to stabilize the mix.

2. Polished Aggregate

Polished aggregates "are aggregate particles in the surface of a pavement that have been polished smooth" (MS-16, 1977), see Figure 22. These can be naturally smooth river washed gravels, or crushed aggregates which have been worn by traffic. These aggregates become slippery when wet causing skid hazards.

Hot in-place recycling can correct a polished aggregate condition with the addition of new aggregate or hot mix. The aggregate or hot mix can be mixed with the reclaimed material in the recycling operation.

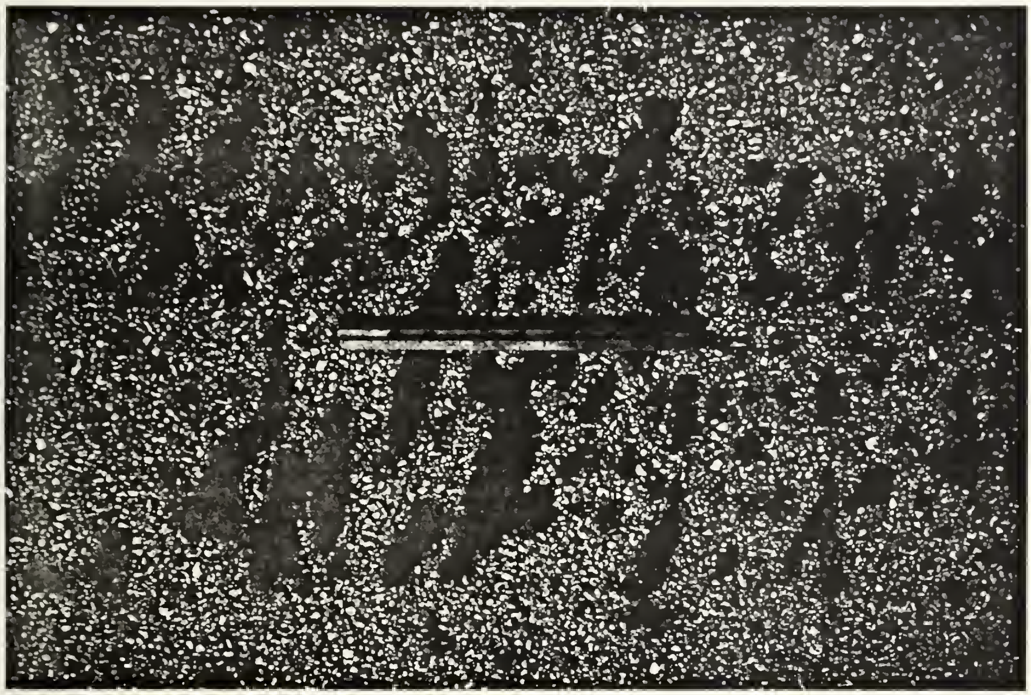


Figure 21. Flushing

Figure 22. Polished Aggregate

V. EVALUATION OF VARIOUS PROCESSES

A. General

This section contains a verbal description of several asphalt pavement hot in-place recycling processes. This selection is not intended to be a list of all the processes available that are capable of performing this type of recycling. The inclusion of these particular processes within this report does not surmise them to be better than those which were not.

Comparison, in terms of economics and finished product, of the different processes in this field of recycling is very difficult due to the uniqueness of each project and each process. Variables such as weather, location, roadway design characteristics, roadway distress characteristics, and roadway usage can have an effect on the finished product and the operation of the process making it difficult to compare two different processes working on separate projects. Each equipment manufacturer of these different processes has a different philosophy for recycling asphalt pavements. These philosophical differences are reflected in each of their processes. Thus, each process is different in design and operation.

B. Cutler Process

Cutler Repaving, Inc. (Cutler) has its main office and manufacturing plant located in Lawrence, Kansas. However, Cutler has exported their process across the U.S. and abroad. Cutler designs, manufactures, and operates their own equipment. The Cutler Repaving process "works over almost all types of existing asphalt pavements: (1) bituminous hot mix, (2) sheet asphalt, (3) seal coated surfaces, (4) slurry sealed surfaces, (5) newly recycled and rejuvenated hot mix" (Cutler advertisement brochure, 1983).

The principle piece of equipment in the Cutler process is called a Repaver. Depending upon the project requirements, a second smaller Repaver and/or a preheater unit may be added to the process. One of Cutlers' operations was observed on a project in Lone Star, Texas, with three types of equipment. The first was a tractor pulled preheater. It heated the pavement surface to about 250 degrees with propane fueled direct flame heaters.

The second unit was a self propelled small Repaver. It applied additional heat to the pavement surface and scarified to a 3/4 inch depth. Modifiers can be metered into the loosened material at this point. The loose surface material is then screeded to hold the heat and provide a better driving surface for the dump trucks supplying the new hot mix to the third unit.

The third unit was a much larger self-propelled Repaver. The new hot mix was dumped into a hopper on the front of the Repaver. The new material can be conveyed to a rear screed. The unit at Lone Star had been specially equipped with milling drums which milled to a depth of 1-1/4 inches. These drums were capable of milling up to two inches of preheated pavement. This was done to remove the previously scarified material in order to combine it with the new material and expose deeper sections of pavement for heating. After another pass of heaters, scarifiers would scarify another 1/2 - 3/4 inches. At this point modifiers can also be dispersed by meter. Mixing augers mix the scarified material and modifier. The blended new and previously milled materials are then spread across the roadway and screeded. The combined recycled and new mix pavement can be between 1-1/2 to 3-1/2 inches in thickness. Compaction is performed by conventional means with steel drum and rubber tired rollers.

Extractions from a Cutler advertisement brochure from Cutler Repaving, Inc. are provided in Appendix A for further information and description of this process. Figure 7 shows this process in operation.

C. Wirtgen Process

Wirtgen GmbH (Wirtgen) of Windhagen, West Germany, is a major manufacturer and operator of asphalt pavement recycling systems. In 1984 Wirtgen had 35 machines around the world. According to Walter Gruber, Wirtgen factory representative, that number has increased to about 55 machines today. Wirtgen designed and built their first machine about 12 years ago. The Wirtgen process was first introduced in this country in 1984 by Remixer Contracting Co., Inc. (Remixer) of Austin, Texas, which is a subsidiary of Wirtgen. Remixer is the sole operator and sales agent for this Wirtgen process in the U.S. Remixer operates 3 of these machines across the country.

"Restoration is accomplished by heating the surface, milling to a predetermined depth, adding new material to achieve the desired specification, and then relaying the material using conventional laydown methods" (Wirtgen advertisement brochure). This involves two units, the first is a preheater and the second is the Repaver/Remixer. The preheater has sections of heaters pinned together forward, mid section, and aft of the tractor. The Repaver/Remixer unit can immediately follow the preheater or they can be separated by a dump truck supplying the new materials. This truck is usually only between the two while it is dumping new material into the hopper on the front of the Repaver/Remixer unit. When the hopper is filled the truck is pulled out from between and travels in front of the preheater unit until the

hopper needs refilling. This is repeated until the truck is empty at which time it is replaced by another truck. The hopper on the Repaver/Remixer can hold about 6 tons of hot mix. The Repaver/Remixer receives the new material, supplies additional heating to the pavement, mills up the old pavement, mixes the new and old materials, and relays the combined material. A lead milling drum mills the heated pavement to a depth of 3/4 inch. The milled material is augered to the center of the Repaver/Remixer allowing deeper sections of the pavement to be heated. Additional milling drums then mill to the specified depth. The milled material is again augered to the center and mixed in a traveling pug mill. It is at this point where the new material and modifiers can be added as prescribed by the design. The thoroughly mixed material is placed in a windrow, augered across the front of the screed, and layed. The mix is then compacted by steel drum and rubber tired rollers.

This Repaver/Remixer is also capable of placing a recycled material mix and a new hot mix overlay in a single pass. Instead of mixing the new material with the reclaimed material in the pug mill, the new hot mix is conveyed above the roadway surface to a secondary screed on the rear of the machine. The new hot mix is placed on top of the screeded recycled pavement and compacted.

According to Remixer's Vice President, Kenneth J.Balchunas, the process is promoted for rehabilitating pavement surfaces to a depth of between 1-1/2 and 1-3/4 inches. However, it is capable of 2 inch depths. The preheater unit heats the top 1-1/2 inches of a pavement to about 180 degrees. The Repaver/Remixer raises that temperature to between 220 and 230 degrees. The operating travel speed is usually between 8 and 12 feet per minute on the average. A maximum of 20 feet per minute has been achieved under special circumstances. The operating width can be adjusted on the move between 10 and 14 feet. The equipment is easily transported by truck and requires about 1 to 2 days setup. The cost of the Repaver/Remixer is about $1 million. The average project cost is about $2 per square yard for a 1-1/2 inch operating depth.

Appendix B has an extraction from a Wirtgen GmbH advertisement brochure for additional information and schematic drawings on the Wirtgen process. Figure 7 shows this process in operation near Lufkin, Texas.

C. Yates Process

The Yates Corporation (Yates), located out of West Columbia, South Carolina, also designs and manufactures asphalt pavement recycling equipment. Yates contracts with contractors across the country to operate their process. The Yates Asphalt Pavement Recycler (YAR) is for sale only to contractors abroad for about $935,000. Yates currently has 2 YAR's in operation with orders for several more over the next few years according to Yates Vice President, Robert Rutland.

The YAR process completely removes the old pavement material off of the roadway in multiple layers. "Working multiple layers requires substantially less heat input than for an equal depth attempted in one operation" (Yates advertisement brochure, 1987). This saves energy and minimizes degradation of the recycled asphalt binder material. The YAR process can include addition of new hot mix and modifiers.

The YAR has a sequence of three stages. The first stage heats and removes the pavement surface. Temperatures of the reclaimed material ranges between 224 and 256 degrees. Removal is performed by milling-mixing augers which place the material in a windrow to be picked up by an elevator and elevated to the mixer unit. The second stage is much the same, except the pavement surface will have been removed. This allows the second bank of heaters to heat the exposed new surface. The idea is that less energy is required to heat thinner layers of the pavement instead of the entire

project depth at one time. The third stage is a little different. The exposed layer of pavement is heated by a third bank of heaters, then scarified, mixed, and left in place.

The YAR has two elevated horizontal mixing units which extend almost the full length of the YAR. The new material, if any, is dumped into a hopper located on the front of the YAR. It is then elevated up into the first mixer unit. The surface material removed by the first stage is also elevated up to the first mixer. A modifier is added to the materials as they enter the mixer. A computerized controller regulates the correct proportions of modifier according to the volume of production. These materials are mixed together and fed into the second mixer. The material reclaimed during the second stage is also fed into the second mixer. All these materials are mixed as they travel the length of the second mixer forming a homogeneous mixture. The combined materials are then dumped into the hopper of a conventional paver, traveling behind the YAR, which lays and screeds the material in place. Conventional steel drum and rubber tired rollers are then used for compaction.

Additional information and schematic drawings of this process have been extracted from a Yates Corporation advertisement brochure and provided in Appendix C.

D. Taisei Process

Taisei Rotec, Inc (TAISEI) of Woodinville, Washington, markets what they call a Heat Reforming Process. "The machines for Heat Reforming Process consist of ... the heating system which can heat the existing asphalt pavement up to 2 inches in depth to a specified temperature without degrading the existing asphalt, and the reconditioning system which can improve existing old pavement materials deteriorated by cracking, rutting, or wearing" (Taisei advertisement brochure).

The Taisei process uses two preheater units and the Taisei Reformer. The Reformer is designed and manufactured by the Taisei Road Construction Company of Japan. The preheaters are built in the U.S., but designed by Taisei of Japan. Taisei does not sell this process or the machines to contractors at this time, rather they operate their own construction subsidiaries such as Taisei Rotec, Inc. Taisei opened its' first operation in the U.S. in 1986. An extraction from a Taisei Rotec, Inc. advertisement brochure is provided in Appendix D for further information.

The Taisei process can be either a remixing or a repaving process. The remixing process uses infared heaters and scarification to loosen the existing pavement. Then, a modifier, if any is used, is mixed with the loosened material by a single hot milling mixer. New aggregate or hot mix is supplied to the Repaver by trucks which dump the new

materials into a hopper located on the front of the Repaver. New aggregate or hot mix is then added and mixed with the old material by a double-axle second mixer. The resultant mix is then screeded to grade and compacted. The repaver process uses the same equipment, but the secondary mixer is usually not used and is raised above the working surface. A new hot mix is then overlayed on top of the recycled mix. Compaction is then performed by steel drum and rubber tired rollers.

The Taisei advertisement states that the process working speed ranges up to 32 feet per minute with 13 feet per minute about average. The working width is adjustable between 10 and 14 feet. Temperatures range from 455 degrees at the surface to 165 degrees at a 2 inch depth scarification.

According to David R. Lovely, marketing representative for Taisei Rotec, Inc., this process has a working unit cost of about $2.50 per square yard for a two inch depth rehabilitation. The process is designed for one to two inch depths of operation. Equipment cost is not listed since it is not available for sale at this time. The equipment is easily transported by truck and can be setup within one day.

VI. PROJECT SELECTION AND DESIGN CONSIDERATIONS

A. General

Producing a quality recycled asphalt mixture requires more care than a quality conventional asphalt mix. The materials to be reused have probably failed in the existing roadway. Thus, consideration must be given to the type and cause of distress, restoration of the salvaged material, history of maintenance and rehabilitation on the roadway to be recycled, environment, traffic, and cost. Considerations must be given to these areas during the sampling, design, and construction phases of a pavement rehabilitation project.

B. Investigation Process

1. General

"Project selection is the first step to asphalt pavement recycling" (Finn, 1980). Several factors, such as contractor availability, economics, energy, engineering design, and pavement condition, should be considered when selecting a pavement rehabilitation method. Finn goes on to say "virtually all asphalt construction can be eligible for the use of recycled materials including new construction, reconstruction, resurfacing, restoration and rehabilitation." However, the right application for a specific condition must be chosen, or failure is sure to follow. This is perhaps the biggest inhibition for recycling asphalt pavements, not knowing which application to use for which type of distress. "It is essential that the cause of the distress that led to the need for recycling be identified and corrected .... It is most important to identify whether these failures are

associated with the characteristics of the mixture to be recycled or with the pavement structure, either locally or in general." (Kennedy and Roberts, 1982). All too often the wrong application is used and failure results. The success of a hot in-place recycling operation depends on the selection process.

2. Site Survey

The job site must be surveyed the same as for any other construction project. This survey should identify and record the current condition of the roadway. It should include a written and visual description of the roadway condition.

The roadway description should identify the type of pavement distress that appears to be occurring. The extent of this distress should be noted, for example: which lane, between what stations, measurements, etc. In general, a deteriorating pavement will exhibit the same distress throughout a common section of pavement. However, it is not uncommon for only a particular section such as intersections, outside lanes, curves, and hills to show distress. For example, a four lane highway may only show distress in the outside lanes due to the larger volume of traffic. In this case, the inside lanes may require a lesser degree of rehabilitation or none at all. Measurements and locations of distress will be important to the design engineer.

Visual aids are always important. They serve as information tools and records. Visual aids include photographs, slides, movies, and video cassettes. In today's world of high technology, video cameras are becoming very popular for entertainment and information purposes. Most construction equipment manufacturing and process companies use videos to promote their product and/or service. Construction contractors and consulting engineers are beginning to use them also. Thus, videos may one day be used to record the condition of an entire roadway in a short time without dozens of photographs to keep track of.

3. Traffic Observation

Traffic observation is often neglected, but is essential for distress analysis and future planning. Knowing the amount and type of vehicular traffic on a roadway will help engineers to determine if the roadway distress is a result of traffic. The existing roadway structure may not have been designed, maintained, and rehabilitated over the years to support heavy truck loads or high traffic volumes. This is very common today in areas experiencing rapid urban growth. Also, knowing this information about the present traffic will enable engineers to estimate future traffic demands. This will help the engineer select the proper roadway rehabilitation method and design to support the predicted future traffic. When faced with higher future traffic requirements, it may be necessary to increase the pavement

depth in order to increase the strength of the roadway system. In this situation, a hot in-place recycling operation would require the addition of new hot mix. The hot mix could be mixed with the reclaimed material to form the surface course, or it could be placed as an overlay on top of the recycled pavement surface.

4. Road Sampling

Taking samples from the roadway is important on any roadway construction operation. Sampling is even more important in hot in-place recycling as it reuses the existing materials. Samples are taken from the existing roadway to obtain materials for the laboratory for testing and analysis. Sample locations should be carefully selected to provide a representative of the roadway. Areas of patching, utility crossing and pot holes, will not be the same mix design as the remainder of the roadway and should be avoided.

The number of samples and amount of material chosen may vary, depending on how representative the samples are and how many and what kind of laboratory tests will be conducted. In general "the engineer should choose at least six sampling sites for each subsection and secure a minimum of 200 lb. of material for each subsequent laboratory analysis" (Kennedy and Roberts, 1982).

5. Records

Files and record drawings of roadways should be consulted when designing any rehabilitation project. This information should be verified by full depth roadway core samples for hot in-place recycling operations. Records and drawings should be up to date showing the design as originally constructed, and all major maintenance and rehabilitation performed on the roadway since it was first constructed.

Good records should also show what problems a roadway has experienced over the years in order to warrant the maintenance and rehabilitation it has received. Such information should be able to pin point problem areas that hot in-place recycling can not correct. A low lying section with a long history of maintenance and rehabilitation would be indicative of water infiltrating the base material. Hot in-place recycling can correct pavement surface irregularities such as alligator cracking, but will not cure the water infiltration problem that may be causing the cracks.

Roadway records should include any information that describes the roadway design, maintenance, rehabilitation, operation, etc. Items like visual aids, traffic counts, drawings, annual inspection reports, etc. would be appropriate for a roadways record file.

6. Field Testing

Field tests to be conducted for a hot in-place recycling operation would be the same used for any conventional rehabilitation project. These tests would be non-destructive tests. The results will enable the design engineer to determine the cause of distress. This information will be used to select the mix design to be used. Field tests should be conducted for structural evaluation, roughness evaluation, and safety evaluation.

C. Mix Design

1. General

The mix design for a recycled asphalt pavement is much more complicated than for a conventional asphalt pavement. The conventional pavement involves development of just one final design. The recycled pavement mix design must consider the existing pavement mix, any new hot mix to be added, and the combined mix. Hot in-place recycling can be used to perform the following:

a. Recycle existing pavement.
b. Recycle existing pavement material and blend with new hot mix.
c. Recycle existing pavement and overlay with new hot mix.

In all three cases the existing pavement mix must be evaluated and tested, to determine how it can be reused in the final pavement design. In most cases, a new hot mix is used in the final design as a conventional overlay, or blended with the existing material to form one design mix.

Generally speaking, the mix design procedure and criteria for a recycling operation are the same as a conventional asphalt pavement mix design. However, "there was and continues to be some question as to whether design criteria originally developed for conventional paving mixtures are applicable for recycled mixes" (Whitcomb, et al, 1981). Whitcomb, et al, evaluated a simplified recycled asphalt mix design which was developed by Witco Chemical Laboratories especially for recycled mixes (Golden Bear Method) and compared it to the traditional Marshall and Hveem methods. The conclusion of their evaluation is "that the numerical values obtained by the Golden Bear Method are roughly the average of the values obtained by the Hveem and Marshall is supportive for the claim that the calculation and nomographs proposed by Golden Bear are good guidelines for the design of recycling operations" (Whitcomb, et al, 1981).

2. Laboratory Testing

Proper design of an asphalt pavement project always includes testing the materials within the laboratory. Recycled asphalt pavements are no different than conventional asphalt pavements in this respect. The design of a recycled asphalt pavement reuses the existing materials which have failed, and usually incorporates new materials such as modifiers, aggregates, and hot mix. "It is essential to evaluate the properties of these [sampled] materials to determine the aggregate and asphalt type [and quantity] that must be used to modify them to meet specification requirements" (Brown,

1982). Thus, the sampled materials must be tested and evaluated prior to selecting and testing of the new materials to be added.

The mix design begins with the sampled materials. The depth of recycling will determine the portion of the sample to be tested. A project requiring only the top 2 inches to be hot in-place recycled, does not require an entire 6 inch deep core sample to be analyzed. The concern is limited only to the material to be recycled. The sampled materials are run through an extraction process to separate the asphalt binder from the aggregate. This will then permit the various material property tests to be performed. The selection of new materials will require laboratory testing to determine their material properties. The results of these tests will determine the type and quantity of modifier, asphalt, and aggregate to be added to the reclaimed material. For example, a highly viscous asphalt binder from a sample will require the addition of a low viscous new asphalt and/or modifier to soften the old binder.

"After the properties of the reclaimed materials and new materials have been determined, the mix design should be performed. The mix design establishes the percentages of each of the various materials to be used in the mixture to ensure that the combined aggregate properties, asphalt properties, and mixture properties are satisfactory" (Brown,

1982). The new mix design properties will be determined from laboratory mixed test samples. Asphalt and aggregate property tests for the new mix design should be run on asphalt and aggregates from the design mix sample. Determining the type and percentage of new aggregate or hot mix is the first step in a mix design. If new hot mix is used, then the second step is to determine the new hot mix design. The third step is to determine the type and percentage of modifier to be used.

"Material and mixture properties used to evaluate and control asphalt mixtures are tabulated below:

> Aggregate - Specific gravity, absorption, L.A. abrasion, soundness, percentage of crushed faced, flat and elongated particles.
>
> Asphalt - Specific gravity, penetration, ductility, viscosity, flash point, thin-film oven test, solubility.
>
> Mixture - Stability, density, voids total mix, voids filled with asphalt, flow, immersion compression." (Brown, 1982)

Gradation was not listed for the aggregates, but it should have been. In addition, Whitcomb, et al, concluded that the "resilient modulus is probably a better guide for pavement stability than the values obtained by the Hveem or Marshall apparatus." The tests above are the standard property tests used by most agencies for conventional hot mix design. An agency's test procedures for recycled mix design should be the same as used in their conventional mix design.

3. Modifiers

The aged asphalt binder existing in most asphalt pavements being considered for hot in-place recycling may be unsuitable in its present form for reuse. Materials called modifiers can be mixed with reclaimed asphalt pavement materials to modify the properties of the old binder in an attempt to restore it as nearly as possible to its original state. These modifiers are also referred to as aromatic oils, extender oils, fluxing oils, recycling agents, rejuvenating agents, and softening agents.

The definition of a modifier is "a material when added to asphalt cement will alter the physical-chemical properties of the resulting binder" (Epps, et al, 1980). The Pacific Coast User-Producer Group uses the term 'recycling agent' which they define as "a hydrocarbon product with physical characteristics selected to restore aged asphalt to requirements of current asphalt specifications" (Epps,et al, 1980). A modifier can be a soft asphalt, various types of oils, or a specifically designed modifier product like the Cyclogen family of modifiers produced by Witco Chemical Corporation. The variety of modifiers available provide a wide range of viscosities and other properties to select from.

According to Epps, et al, the purpose of a modifier in recycling of asphalt pavements is to:

> 1. "Restore the recycled or 'old' asphalt characteristics to a consistency level appropriate for construction purposes and for the end use of mixture.
>
> 2. Restore the recycled asphalt to its optimal chemical characteristics for durability.
>
> 3. Provide sufficient additional binder to coat any new aggregate that is added to the recycled mixing.
>
> 4. Provide sufficient additional binder to satisfy mixture design requirements." (Epps, et al, 1980)

A modifier is not a cure all for aged asphalt pavements, nor is any one type the best one. "The effects of different modifiers on a specific asphalt are different. Conversely, the effects of a specific modifier on different asphalts are different, therefore, a single relationship cannot be valid for general use" (Jones, 1978).

It is the pavement design engineer's job to select the modifier best suited to perform the tasks above such that when mixed with the old asphalt binder, it will produce a durable binder for the selected recycled mix design. "Modifier properties of interest to the engineer are those

that can be used for specification purposes to ensure that the modifier will perform the following functions:

1. Be easy to disperse in recycled mixture.

2. Alter viscosity of old recycled asphalt cement to desired level.

3. Be compatible with the old recycled asphalt to ensure that syneresis (exudation of parafins from asphalts) will not occur.

4. Have the ability to redisperse the asphaltenes in the old recycled asphalt.

5. Improve the life expectancy of the recycled asphalt mixture.

6. Be uniform in properties from batch to batch.

7. Be resistant to smoking and flashing if used in hot mix operations." (Epps, et al., 1980)

A modifier capable of softening brittle asphalt binder would be used for pavements with cracks to decrease binder viscosity and increase penetration values. Penetration values above 45 are desirable. When adding new asphalt or modifier to an existing asphalt material, the design engineer must be aware that "any material that mixesand amalgamates with the asphalt in a pavement increases the amount of the bituminous binder in the pavement" (Jones, 1978). If this is ignored the resulting mix will be too rich in asphalt.

4. Aggregates

New aggregates are added in recycling operations to perform one or more of the following:

1. "To satisfy gradation requirements;
2. To improve the skid resistance to meet requirements for the new surface course;
3. To meet air-quality regulations associated with hot central plant recycling, typically 30 to 40 percent new aggregate [or more];
4. To meet total pavement thickness requirements;
5. To improve the properties of the mixture, such as stability, durability, and flexibility; and
6. To be able to add enough modifier to restore the salvaged asphalt to meet specification requirements and still maintain required mixture properties. (Epps and Holmgreen, 1980)

While the above items were listed by Epps and Holmgreen in relation to central plant recycling, the same hold true for hot in-place recycling.

Item 3 refers to the practice of heating new aggregate in a central plant, then adding the reclaimed material to the heated new aggregate in order to heat the reclaimed material. This keeps the reclaimed material asphalt binder from coming into contact with the burner flames of a drum dryer. This would result in burning the asphalt binder and producing 'blue smoke.' While hot in-place recycling processes do not involve central plants, they do not create a lot of smoke. This is particularly true for high asphalt content pavements

and pavements with seal coats. New aggregate could be spread on a pavement surface ahead of the heaters in order to hold down air pollution. The heater flames would heat the new aggregate on the surface without contacting the pavement surface. This is probably not very practical or necessary unless the pavement surface has a seal coat. Seal coats produce excessive smoke (air pollution) when heated during hot in-place recycling operations. Sand would probably be better in this application than gravel size aggregates. This practice has not been documented very well, but "could be helpful on surface seal coats" (Rudd, 1987).

The addition of new aggregate during hot in-place place recycling operations is not very popular in this country. However, "the addition of new aggregate is widely accepted in other countries, particularly in the European countries" (Gruber, 1987). Most recycling operations in the U.S. add new hot mix to the reclaimed materials to accomplish items 1, 2, 4, 5, and 6 above. The new hot mix is specifically designed as needed to accomplish those items. The gradation and type of new aggregate selected for this new hot mix is very important for attaining those results.

D. Other Considerations

1. Contractor Availability

Most roadway construction contractors do not own the highly specialized hot in-place recycling equipment. Many manufacturers restrict the availability of this equipment only to their subsidiaries or a selected few contractors. The cost of the equipment is very expensive, which drives some contractors away. They don't see a big enough market for hot in-place recycling to warrant that kind of investment.

This obstacle would probably be eliminated if more contracting agencies would become interested in hot in-place recycling. Many agencies currently have specifications which allow the use of a specified maximum percent of reclaimed mix on new overlays and base reconstruction projects as an option to the contractor. As a result central plant hot mix recycling is being passively promoted. However, hot in-place recycling usually has to be specifically specified. An example of a specification, Special Specification, Item 3199, Asphaltic Concrete Surface Rehabilitation, used by the Texas State Department of Highway and Public Transportation on a project outside Lufkin, Texas, in June 1987 is provided as Appendix E.

Many writers consider contractor availability as a factor of consideration and rightly so. However, I think many agencies make it an obstacle. If the agencies actively promoted and encouraged hot in-place recycling, the contractor community would respond accordingly.

Hot in-place recycling contractors are available all across this country. In most cases they are not the nearest local contractor, but they are highly mobile. Most hot in-place recycling contractors travel extensively in order to stay in business, because of the small number of hot in-place recycling projects put out for bids. Many contractors are expanding their operations as more and more projects are being advertised.

2. Cost And Energy

The lowest cost of the rehabilitation alternative meeting the requirement is usually the one selected by the design engineer. In the last 15 years, energy has played a major role in the cost of a project. When the required amount of energy can be reduced, the project cost is usually reduced also. Roadway construction and rehabilitation methods are very energy intensive. Large amounts of energy are expended through mining materials, transporting materials to and from process locations, transporting to project site, and putting the material in place. Hot in-place recycling can have a big advantage in this area, especially if the project site is remote.

3. Governmental Regulations

Governmental regulations must always be considered. Regulations on air pollution, land use, noise, and safety are increased every day. These regulations can have a big impact on cost and feasibility of a recycling operation.

Air pollution has been a problem with some hot in-place recycling operations. Improvements as a result of equipment modification and new technology have helped. However, some parts of the country will not permit some of these hot in-place recycling operations.

F. Engineering Considerations

The impact, if any, and feasibility concerns could disqualify a hot in-place recycling operation as a rehabilitation alternative. Hot in-place recycling would have to be compatible with the roadway design data gathered from the site survey and records search. The existing roadway surface may contain loop detectors, manhole covers, paved over railroad tracks, high sulfur content in the asphalt binder, seal coats, etc. This list is too numerous to try to identify and discuss each possible problem or concern. However, identification of these kind of concerns could be critical to a hot in-place recycling project.

VII. CONSTRUCTION CONSIDERATIONS

A. General

The quality of a recycled pavement can be affected to a large degree by the construction methods and machinery used during construction of the project. A close look at the way a particular hot in-place recycling process heats, scarifies/mills, modifies, mixes, and relays the existing pavement can identify areas of concern that should be watched very closely during construction. These differences in the various processes and the general characteristics of this type of recycling may also need to be considered in the design phase of a project. "One of the major concerns of engineers with regards to the use of recycled materials is construction control. Because of the high variability of salvage materials or handling techniques, uniformity may be somewhat more of a problem in recycling than it would be for conventional materials" (Lee, et al, 1983).

B. Heating

There are two predominant methods of heating a pavement in hot in-place recycling: direct flame and indirect heating. The direct flame method used to be the only method. The indirect heating method is the most popular method used by contractors and equipment designers today. There is some debate within the recycling community concerning which is the best method of heating.

The quality control and method of heating the asphalt pavement is very important. The heat changes the engineering properties of the old asphalt binder, making it more workable. The application of too much heat or too little heat can permanently change the properties of the existing pavement materials. Too much heat can destroy the asphalt binder, especially if it is heated above its flash point. Too little heat can cause fracturing of the aggregate in the existing pavement, and inability to obtain proper compaction. The efficiency is also affected by the temperature; as too much is wasteful and too little slows down the process.

The purpose of heating the pavement is to make the existing pavement material workable. Heating the pavement allows the scarification teeth or milling augers to break up the pavement and mix it with new materials. It is believed that a hot process results in a better product than a cold process. The heat enables more efficient mixing which means better material bonding, coating, and compaction.

C. Scarification/Milling

The methods of breaking the pavement surface up in hot in-place recycling operations are scarification and milling. Scarification has been around almost since the beginning of recycling work. Scarification of the pavement surface is produced by teeth or tines which drag through the heated, soft pavement at a set depth. This loosens the material for mixing, adding new material, and replacing.

The pavement milling method is refered to as a hot milling process since it is preceded by heaters and it mills up the hot pavement. This milling usually performs two operations: removing the heated pavement and augering the material. Hot milling is becoming very popular with contractors and equipment designers. Another area of debate within the recycling community is whether scarification or milling is better for this application.

D. Modifiers

The type of modifier, if any, used can affect the recycling operation and the end product. As discussed earlier there are numerous kinds of modifiers. The type and amount of modifier should be evaluated during the recycling operation to insure it is doing what it was intended to do. Changes may be needed due to changing road conditions or wrong selection at beginning of the project.

Some modifiers are emulsified asphalts which are defined by the Asphalt Institute, manual series No. 5, as "an emulsion of asphalt cement and water that contains a small amount of an emulsifying agent, a heterogeneous system containing two normally immiscible phases (asphalt and water) in which the water forms the continuous phase of the emulsion, and minute globules of asphalt form the discontinuous phase." Since an emulsion is water based, more heat is required during the

process to drive off the water. Emulsions tend to be unstable at times, making it difficult to produce a uniform mixture. If the water breaks prematurely in the tanks, this will produce patches of lean and rich mixtures of recycled pavement. This will also cause the modifier dispensing system to clog up, which results in down time and an undesirable product. The shelf life of the emulsion must also be considered. This can cause inventory problems for the contractor and is a must inspection item for the inspector.

As a result of these problems with emulsions, commercial modifiers and asphalt oils are becoming more popular. Commercially developed modifiers are often individually unique. Users should be familiar with these products and follow the manufacturers' suggestions. Asphalt oils require heating, but are otherwise uncomplicated.

E. Mixing

The purpose of mixing is to produce a homogeneous mixture. "The mixing of bituminous materials should accomplish two things: the various-sized particles of aggregate and asphalt cement must be properly distributed and the particles properly coated" (Lee, et al, 1983). The method of mixing the existing and new materials to produce the recycled asphalt pavement is one of the major differences among the various types of hot in-place recycling equipment. Most mix

the materials on the roadway, of which there are numerous methods, while other completely remove the existing material off the roadway for mixing.

The effectiveness of the modifiers added in a process is dependent upon its contact with the existing aged asphalt binder. The difficulty comes with adding such a small amount of modifier, usually about 0.1 - 0.3 gallons per square yard of pavement. Mixing such a small amount of liquid in a field operation can easily result in rich spots. Field mixing does not always match central plant or laboratory efficiencies. If the existing material is very dry, it may absorb the liquid modifier very quickly, and not allow it to be dispersed evenly throughout the material.

Determining the adequacy of mixing during the operation is a problem. "As a rule of thumb, the mixing efficiency is generally measured by the appearance of a bituminous mixture in terms of distribution and coating. However, the similarity of rejuvenating agents and the original asphalts themselves is such that detection of one combined with the other may be very difficult" (Lee, et al, 1983). Lee, et at, performed a study on mixing efficiency. The conclusion was that the resilent modulus test, performed in a laboratory, is the best measure of mixing efficiency as it varies according to the asphalt binder properties.

F. Relaying and Compacting

Relaying of recycled asphalt pavements with these hot in-place recycling processes is generally no different than conventional asphalt pavement overlays. The methods and equipment for relaying are essentially the same as that of a conventional hot mix paver machine. The Yates process discussed earlier even uses a conventional paver in its process.

The methods and equipment for compacting recycled pavements are the same as with conventional hot mix pavements. Both use a steel drum roller immediately following the laydown operation. This is followed by a rubber tired roller. Since the temperature of recycled pavements tend to be lower than conventional overlays, the steel drum roller may need to follow closer behind the laydown operation to obtain proper density. This is where many recycling operations tend to miss the mark.

G. Testing

During the construction phase, laboratory testing should be performed on both the new hot mix and the recycled mix. The testing for the new hot mix, if any is used, will be the same as for a conventional asphalt overlay project. The testing for the recycled mix will be very similar, including the same property test and including a couple of others. The samples from the recycled mix will have to be obtained in the field at a specific point in the process. These samples should be

taken at the rear of the operation after all the mixing has been performed to insure a good representative sample. Depending upon the configuration of the process, this could be a problem if the location on the equipment is not easily accessible. Such samples could be taken after the material has been screeded. "A summary of the tests required in the field laboratory for conventional mixtures and recycled mixtures is listed below:

> Both Mixtures - Marshall compaction and test: stability, flow, density, voids total mix, and voids filled with asphalt; aggregate gradation; asphalt extraction, temperature, density: laboratory and field cores.
>
> Recycled Asphalt Mixtures - Asphalt recovery; asphalt penetration." (Brown, 1982)

Refering back to the discussion in the Mixing section, the resilent modulus test is the best test for determining the efficiency of the mixing process for maximum modifier contact with the old asphalt. Thus, the resilent modulus test could be added to the tests above for both mixes.

VIII. CONCLUSIONS

The transportation network in this country is being challenged. This country has a big investment in our network of highways, roads, and streets. As a result of age, neglect, and increased traffic demand, this transportation network is deteriorating faster than the roadways can be rehabilitated. Over the years, the availability of new materials have decreased, and the cost of available new materials have drastically increased. Rehabilitation costs have also skyrocketed. Recycling of asphalt pavements is one rehabilitation technique that can ease availability and cost problems.

The use of recycling as a rehabilitation alternative is not new, but has become very popular over the last twelve years. There are three types of recycling classifications: surface, central plant, and in-place. Each has proven their effectiveness when applied properly. Each roadway distress situation must be matched with the proper type and method of recycling, or the rehabilitation attempt will be a failure.

A relatively new type of recycling operation, hot in-place recycling, is becoming very popular, and is proving itself as an effective technique. It is capable recycling the top two inches of an asphalt pavement on the roadway. The selected processes described in this report are examples of the variety of equipment process technique being used.

There are a number of items that must be considered when selecting hot in-place recycling for a project: hot in-place recycling process itself, roadway design, roadway distress, design process, and performing the work. Without proper consideration, such projects are invitations for disaster.

Hot in-place recycling is not a cure all. However, it has proven its effectiveness when properly matched with the appropriate situation. This type of recycling will continue to improve in popularity and capabilities.

IX. RECOMMENDATIONS

Recommendations for further study are:

1. Evaluate how much destruction is sustained by the asphalt binder in an asphalt pavement from the heat and flames of a hot in-place recycling operation, and what effect that will have on the recycled mixture.

2. Determine the effects of hot in-place recycling of an asphalt pavement more than once.

3. Development of an expert system for hot in-place recycling.

4. Evaluate the experience of other countries regarding hot in-place recycling, particularly Japan and the European countries.

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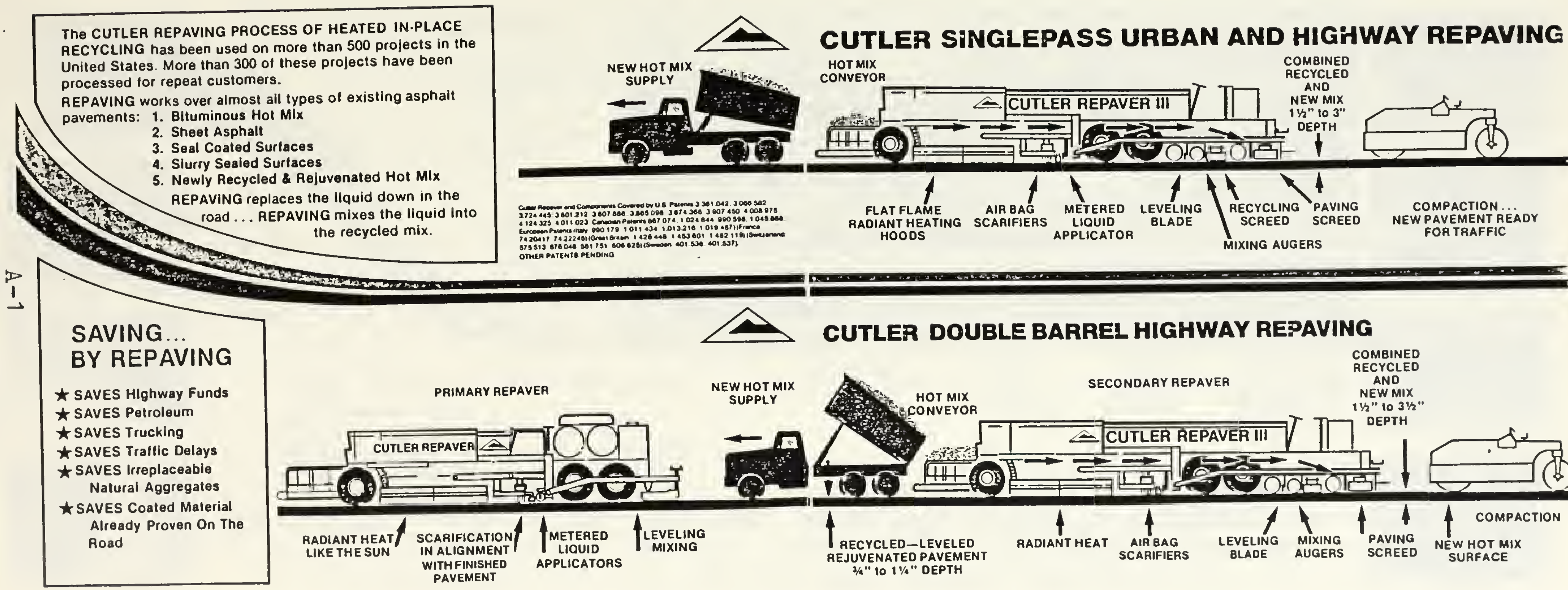
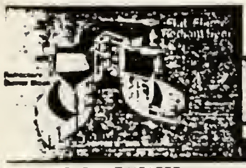
APPENDIXES

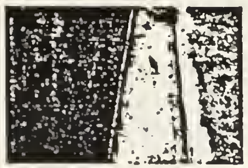


(From Cutler Repaving, Inc. Advertisement Brochure)


RADIANT HEATER


SCARIFYING—MIXING—LEVELING


SEAM CUTTER


FLUSH WITH CURB APRON

CUTLER REPAVER III

NEW DUAL
HOT MIX CONVEYORS
150 TPH CAPACITY

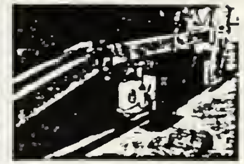
ALL WHEEL DRIVE

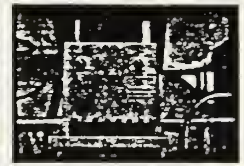
ALL WHEEL STEER

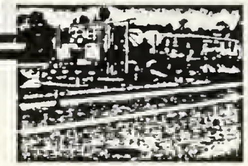
42 RADIANT FLAT
FLAME HEATERS
18,000,000 BTU
CAPACITY

CUTLER
REPAVER III . . .

ENGINEERED TO HEAT
AND RECYCLE RIGHT
ON THE ROAD


POSITIVE SPINNER APPLICATOR


DIAL LIQUID CONTROL


WALKING BEAM


MOVING

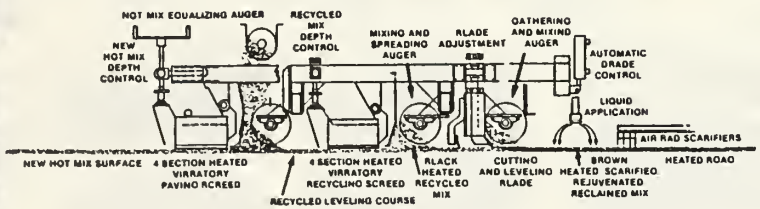
SCARIFICATION
3/4" TO 1 1/4" DEPTH

METERED
LIQUID
APPLICATION

SCREED
POSITIONED
LEVELING
BLADE

1 1/2" TO 3 1/2"
COMBINED DEPTH
OF RECYCLED
AND NEW HOT MIX

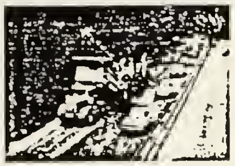
CUTLER 3 STEP LEVELING AND RECYCLING SYSTEM



A HIGH PRODUCTION FACTORY ON WHEELS
PROVEN BY 18 YEARS OF EXPERIENCE ON
CITY STREETS, HIGHWAYS AND AIRPORTS!

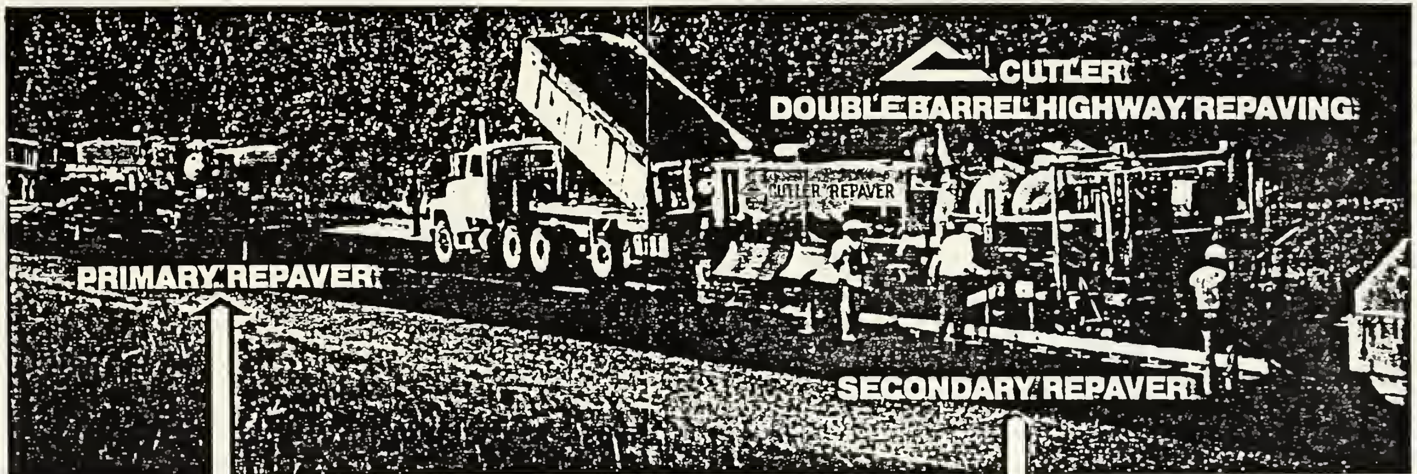
PROVEN BY MORE THAN 6,000 MILES OF PRODUCTION ON THE PAVEMENTS OF THE UNITED STATES AND WESTERN EUROPE

MATAMOROS, MEXICO



CONNECTICUT—MERRITT PARKWAY

MARSEILLES, FRANCE



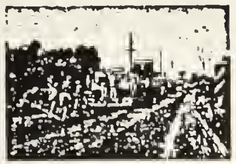
1 RADIANT HEATING
2 SCARIFICATION ¾ TO 1"
3 METERED LIQUID APPLICATION
4 LEVELING MIXING
5 SCREEDING TO 85% COMPACTION

6 RADIANT HEATING
7 SCARIFYING 1" TO 1¼"
8 LEVELING MIXING
9 LAYING ¾" TO 2½" NEW HOT MIX TO 85% COMPACTION
10 GRADE AND SLOPE CONTROLS
11 DEPTH BEHIND SCREED 1½" TO 3½"
12 COMPACTION 98% + DENSITY

ALBUQUERQUE, NEW MEXICO

TOPEKA, KANSAS

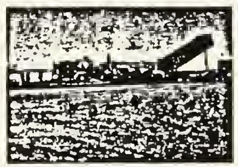
WICHITA, KANSAS



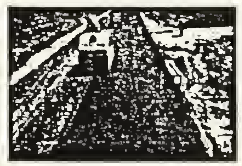
KANSAS HIGHWAY 58

TAOS, NEW MEXICO

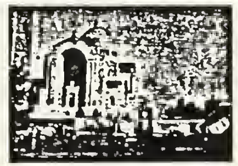
AUSTIN, TEXAS



ALBUQUERQUE AIRPORT

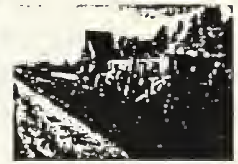


KANSAS HIGHWAY 56



WASHINGTON, D.C.

MALMO, SWEDEN

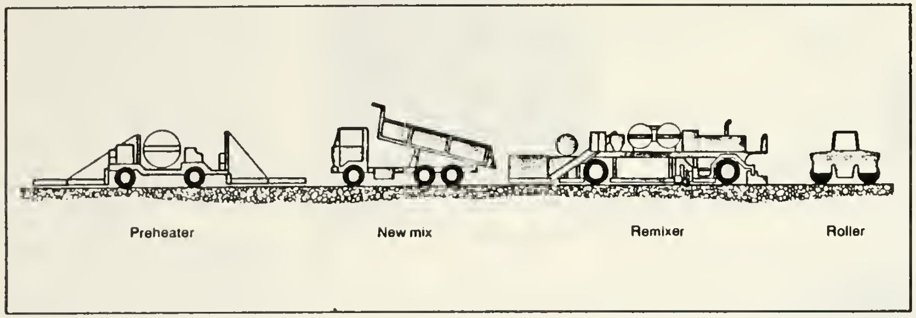


ALABAMA HIGHWAY 231

Mobile in-place hot mix recycling
Remixing – Repaving

Use of the Remixing – Repaving techniques provides the ability to restore surface course material on-site. Restoration is accomplished by heating the surface, milling to a predetermined depth, adding new material to achieve the desired specification, and then relaying the material using conventional laydown methods.

Because existing materials are reused and the resurfacing work is done on-site, considerably less raw materials and energy are required than when using conventional overlays. Remixing in-place is a valid and competitive alternative to central plant recycling.

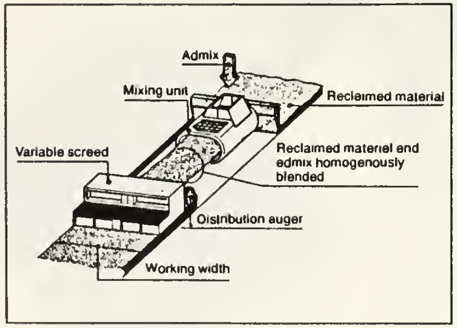


The Remixing Process

Remixing is accomplished by using a preheating unit and the remixing unit.

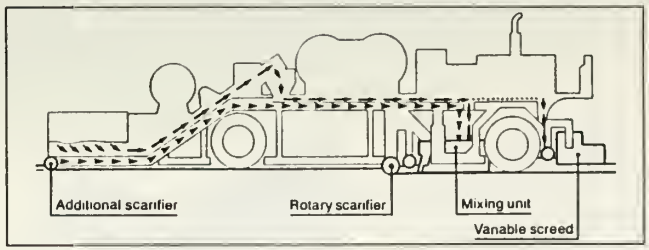
The Preheater is a separate unit and provides initial preheating of the surface which is then milled to a depth of ¾" by the lead milling drum mounted on the Remixer. Material milled is augered to a center collecting conveyor, leaving deeper surfaces exposed to heaters mounted on the Remixer. This surface is then milled to the required depth by the two mid mounted rotating drums. The milled material is then augered to the center of the machine and fed into a pugmill mixer where reclaimed material (milled by the leading drum) and the new mix are combined and thoroughly mixed.

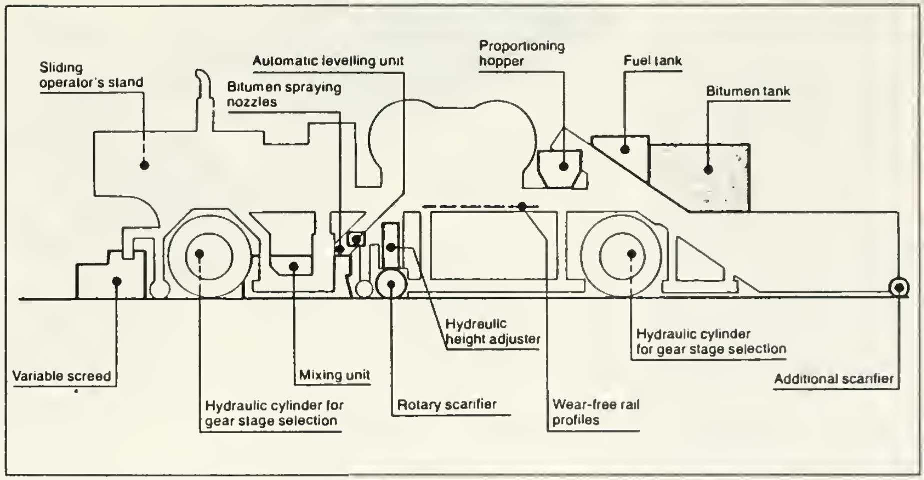
Recycling asphalts can also be added at this point.



The remixed material is then discharged from the pugmill in a windrow and distributed in front of the screed by an auger. The process is then completed by screeding and rolling the material as in conventional methods.

The resulting new asphalt mix and restoration process has then been completed, having achieved the desired mix characteristics and surface texture.





The Repaving Process

This can be achieved by augering the milled material to the center of the machine and into the pugmill where it is mixed, if necessary, with a recycling agent. This recycled mix is then spread out and compacted by a primary auger and screed. At the same time the new mix is fed by the conveyer directly to the near auger and screed where it is spread and compacted on top of the recycled material. The process is then completed by rolling the materials as in convertional methods. Repaving can be used where the existing pavement material is suitable for reuse with the addition of a recycling agent only and no additional hotmix aggregate.

(From Wirtgen GmbH Advertisement Brochure)

The Process

The patented "YAR" process and machine are results of over four years of dedicated research, design, development, testing, modifications, retesting, trial projects, and evaluations by independent experts.

It cost less to buy and to operate. It recycles more of the old material faster. It produces a finished product with better chemical and physical properties, and a longer service life than any other asphalt concrete pavement surface restoration method.

The reason for this revolutionary improvement in productivity and quality is because of the ability to heat, soften, and completely remove the old material with multistage operations within the "YAR". Why? Working multiple layers requires substantially less heat input than for an equal overall depth attempted in one operation. This lesser volume of heat minimizes thermal effects on the top face of the pavement and prevents any disturbance to the binder in the compacted mass below the face.

As each softened layer is auger stripped away, the hot material on the top face is instantly mixed with the warm underneath. This creates a quick, homogeneous, and harmless 120°C to 140°C (224°F to 258°F) temperature in the recycling mix. This is only 50% to 55% of the minimum flash point of asphalt binder. These milling-mixing augers also move the material to a central windrow.

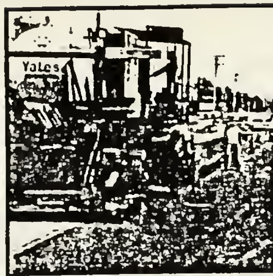
The aggregates in this softened zone come loose easily. None are broken, therefore the wear course aggregate gradation balance is maintained through the process. There is no need for make-up aggregates, as is required by methods that fracture these load carrying materials.

Complete removal of the old material to a plane below surface irregularities evenly profiles the pavement. Elevators raise the depleted asphalt concrete to a long remixing system. The programmable controller's computer measures the volume of material being recycled and meters in a rejuvenating agent selected to restore elasticity and durability. The still high temperature of the recycling material, the special mixing action, and the long dwell time permit thorough reaction of the rejuvenator with the deteriorated binder. This avoids instability in the recycled pavement, which is sometimes the case in processes that use emulsions or no heat.

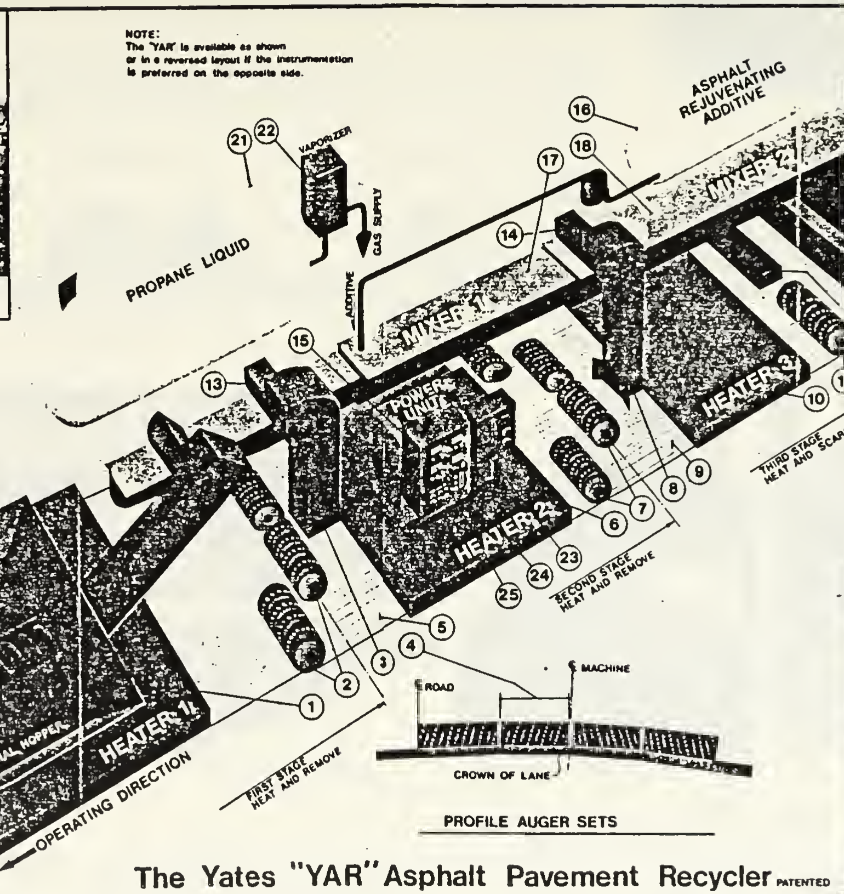
After remixing, the revitalized material is layed and compacted with a conventional paver and tandem roller. Because this is hot, rejuvenated, and at a depth twice the largest aggregate size, it is easy to achieve the optimum compaction density and finish. This has been achieved with two forward and back passes of a single roller.

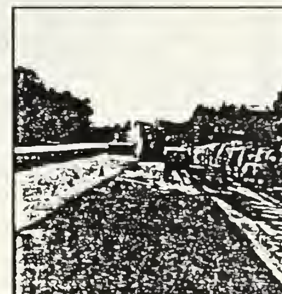
The restored pavement will have properties of a totally new mix overlay job. This means the "YAR" process can be specified and applied as an equivalent alternate to all new mix. In reality, it is better, as the base is releveled, the overlay is hot bonded to the old surface, and the edge(s) is hot bonded to the adjacent lane(s).

A new mix hopper is available for jobs where there is a need for structural reinforcement of the existing pavement by addition of some new solid materials



Adjacent lanes are bonded together with a heated joint overlap.





The mat after recycling of a badly rutted highway truck lane

The Machine

In sequence, the first stage heater (1) softens the old pavement surface as the "YAR" moves across it from right to left in the drawing.

The operating width adjustable multiple milling-mixing augers (2) strip the hot, softened old mix into a windrow which feeds into the elevator (3). The independently suspended augers (2) are adjusted by the operator to strip the depth required by the job specifications. The short length of each auger (4) allows the stage to follow a crown closely and make an even depth cut across the lane width. Gradation is not affected as existing aggregates are not broken in this hot milling process.

The newly exposed surface (5) is then softened by the second stage heater (6) and stripped by milling-mixing augers (7) and feed into elevator (8).

The final layer (9) is softened by the third stage heater (10). It is then scarified and mixed with rotary (11) or drag (12) devices and left in place. Its high temperature assures that a homogeneous bond to the undisturbed base will occur when the recycled materials are layed over it and compacted.

The stripped materials from the first and second stages travel through measuring bins (13) (14) where a total weight per minute rate is determined.

The programmable controller's computer (15) uses operator ratio settings to calculate and dispense a proper volume of the asphalt rejuvenating agent (16) necessary to chemically restore the mix.

The recycling materials then travel through mixers (17) (18) to the standard paver for laying and then recompaction by a conventional tandem roller.

On some projects the specifications might require the addition of new aggregates. In that event, the computer (15) can meter out new material from the hopper (19) with a variable rate screw (20). This can be done relative to machine speed, or by volume of the materials being recycled.

The propane tank (21) and vaporizer (22) provide premixed gas-air fuel to the heaters through a fail safe system of valves and regulators. The volume of fuel to each heater is infinitely and immediately controllable by the operator (23).

A data terminal (24) at the operator station receives information from the programmable controller and is set to print out a hard copy of process conditions at intervals of time or distance traveled. Typical data includes date, time, station mark, job number, crew number, material recycling rates, volume to date for the job, active temperatures, additive amounts used in the current run and on the job, propane use rate and volume, new materials used, and so on. This feature provides excellent means of process quality control auditing for the contractor and client.

In-process instrumentation (25) on the machine provides the operator with all the data accessed by the data terminal plus the ability to regulate machine speed, steer, adjust heaters, set the additive ratio, set the new mix ratio, audit temperatures, start and stop any function, etc.

(From Yates Corporation Advertisement Brochure)

Heat Reforming Process is the best method for in-place pavement rehabilitation

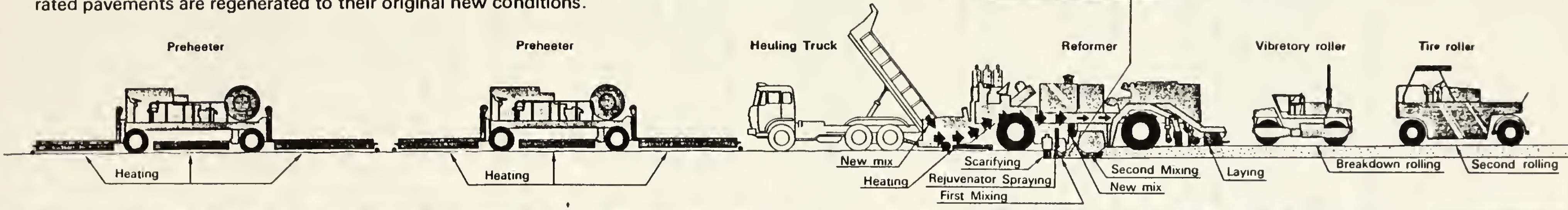
The machines for Heat Reforming Process consist of, as shown below: the heating system which can heat the existing asphalt pavement up to 2 inches in depth to a specified temperature without degrading the existing asphalt, and the reconditioning system which can improve existing old pavement materials deteriorated by cracking, rutting or wearing.

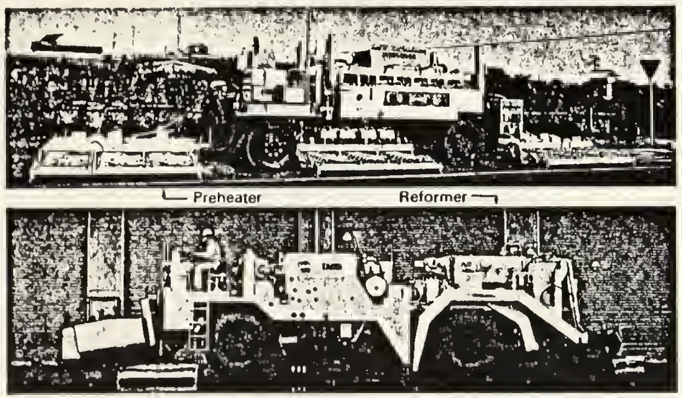
The Reformer is also equipped with the new mix supplying device which can make new homogeneous monolithic layers.

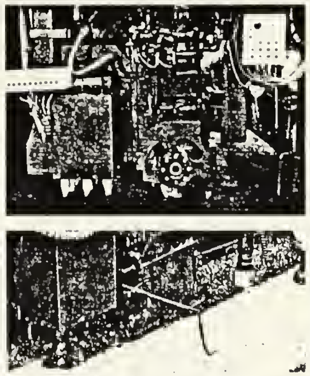
Rehabilitation work can be performed with this Process in one pass within a short time, by which deteriorated pavements are regenerated to their original new conditions.

Principal Dimensions of Heat Reformer

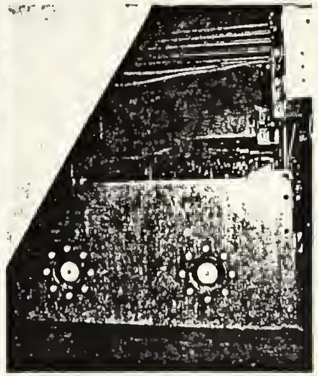
Item \ Machine	Heat Reformer: Preheater	Heat Reformer: Reformer
Total weight	16.0 t	35.0 t
Total width	2,950 mm	2,450 mm
Total length	13,600 mm	13,000 mm
Total height	2,800 mm	2,850 mm
Working width	300 ~ 450 cm	300 ~ 420 cm
Heating unit	LPG-Infrared	LPG-Infrared
Heating capacity	3,718,000 Kcal/h	616,000 Kcal/h
Scarifier stroke		0 ~ 100 mm
Working speed	0 ~ 10 m/min	0 ~ 10 m/min



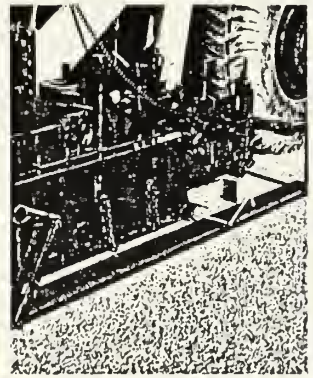




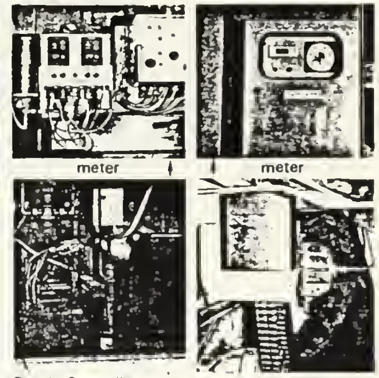
Scanfier and First Mixer



Double-Axle Type Second Mixer



Levelling Sensor



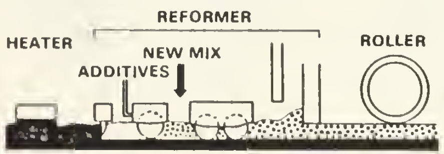
Depth Controller and Sensor

Thermometer and Sensor

REMIX

Applied to recondition existing surface course materials deteriorated by rutting or cracking.

The old weanng course is heated, loosened, mixed with rejuvenator in the case of cracking, or with oil-absorbing aggregates in the case of rutting by plastic flow, or with new esphalt mix as required.

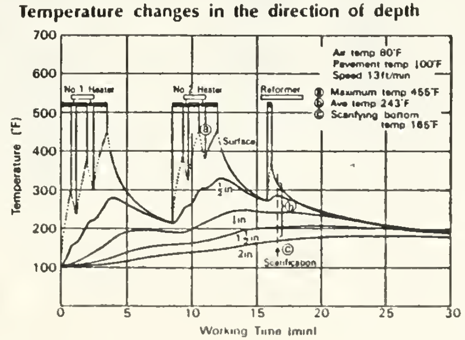


REPAVE

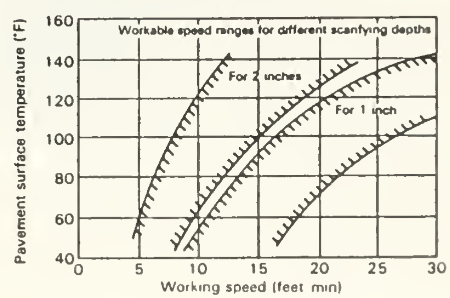
Applied to the worn or slippery wearing course or to the pavement requiring upheaval.

The old wearing course is heated, loosened and reprofiled, on which new asphalt mix is laid to a required thickness, rolled together with hot loosened underlying old asphalt, and finished by rolling into a one layer.

Temperature changes in the direction of depth



Relation between pavement surface temperature and working speed



(From Taisei Rotec, Inc. Advertisement Brochure)

SPECIAL SPECIFICATION

ITEM 3199

ASPHALTIC CONCRETE SURFACE REHABILITATION

1. Description. This item shall govern for asphaltic concrete surface rehabilitation, a process that consists of softening the existing asphaltic concrete surface with heat, scarifying to the depth shown in the plans, and thoroughly remixing and leveling scarified material. Blending of scarified material with additional aggregate or fresh hot mix asphaltic concrete will be required.

   All work under this item shall be in conformity with the typical sections shown on the plans and to the lines and grades as established by the Engineer.

2. Materials. Additional aggregate or fresh hot mix asphaltic concrete will be furnished to the Contractor free of charge at a location shown on the plans.

3. Equipment.

   a. Processing Equipment. The equipment for heating, scarifying, remixing, and repaving shall be as approved by the Engineer. The equipment shall consist of the following, either as a complete unit or in approved segments:

      (1) A heating mechanism capable of heating the asphaltic concrete pavement surface to a temperature high enough to allow scarification of the material without breaking aggregate particles, without charring the pavement, and without producing undesirable pollutants. The heating mechanism shall be so equipped that heat application shall be under an enclosed or shielded hood.

      (2) Scarifier sections capable of uniformly loosening the asphaltic pavement.

      (3) A leveling unit capable of gathering the heated and scarified material into a windrow or otherwise collecting for remixing, and of distributing over the width being processed and finishing so as to produce a uniform cross-section and surface.

      (4) A system for adding and uniformly blending addi tional aggregate or fresh hot mix asphaltic concrete. The application rate for the additional material shall be sychronized with the machine speed to provide uniform application.

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b. Rollers. Rollers shall be in accordance with the Item "Hot Mix Asphaltic Concrete Pavement".

4. Construction Methods. The pavement surface to be rehabilitated shall be cleaned of all dirt and other objectional material by blading, brooming or other approved methods, prior to beginning heater-scarification operations.

The pavement surface shall be evenly heated, scarified and remixed to the widths and depths shown in the plans. Heating shall be controlled to assure uniform heat penetration without causing differential softening of the surfaces. Charring of the asphalt will not be permitted. The scarified material shall be gathered by the leveling device, uniformly mixed with the added material, and relaid. The rate of application of added material shall be as determined by the Engineer.

The heated and scarified material shall have a temperature in a range between 200 F and 265 F as measured immediately behind the scarifier. The Engineer will select the temperature within these limitations, and the mixture shall not vary from this selected temperature by more than 25 F and shall remain within the above limits.

There shall be no burning of trees, shrubs, or other landscaping adjacent to the pavement. It shall be the responsibility of the Contractor to protect the adjacent landscape from heat damage. This protection may consist of individual shielding and/or water spray or other methods approved by the Engineer.

When a pass is made adjacent to a previously placed mat, the longitudinal joint shall extend at least 2 inches horizontally into the previously placed mat, unless otherwise directed by the Engineer. Other methods approved by the Engineer may be used that insure a tight joint between the mats.

Compaction will begin before the reclaimed or blended paving material temperature drops below 190 F. All rolling shall be completed before the mixture temperature drops below 175 F unless determined by the Engineer that a higher temperature is required for proper compaction.

When rolling with the three-wheel, tandem or vibratory rollers, rolling shall start longitudinally at the sides and proceed toward the center of the pavement, overlapping on successive trips by at least half the width of the rear wheel unless otherwise directed by the Engineer. Alternate trips of the roller shall be slightly different in length. On super-elevated curves, rolling shall begin at the low side and progress toward the high side unless otherwise directed by the Engineer. When rolling with vibratory steel-wheel rollers, the manufacturer's recommendation shall be followed unless directed otherwise by the Engineer. Rolling with

pneumatic-tire roller shall be done as directed by the Engineer. Rolling shall be continued until no further compaction can be obtained and all roller marks are elimi nated. One tandem roller, one pneumatic-tire roller and at least one three-wheel roller, as specified above shall be provided for each job unless otherwise directed by the Engineer. If the Contractor elects, he may substitute the three-axle tandem roller for the two-axle tandem roller and/or the three-wheel roller. Additional rollers shall be provided if needed. With approval of the Engineer, the Contractor may substitute a vibratory roller meeting the requirements of this specification and operated in the manner prescribed herein. The motion of the roller shall be slow enough at all times to avoid displacement of the mixture. If any displacement occurs, it shall be corrected at once by the use of rakes. The roller shall not be allowed to stand on pavement which has not been fully compacted. To prevent adhesion of the surface mixture to the roller, the wheels may be kept moistened with water, but an excess of water will not be permitted. All rollers must be in good mechanical condition. Necessary precautions shall be taken to prevent the dropping of gasoline, oil, grease or other foreign matter on the pavement, either when the rollers are in operation or when standing.

In lieu of the rolling equipment specified, the Contractor may, upon written permission from the Engineer, operate other compacting equipment that will produce equivalent relative compaction as the specified equipment. If the substituted compaction equipment fails to produce the desired compaction as would be expected of the specified equipment, as determined by the Engineer, its use shall be discontinued.

The edges of the pavement along curbs, headers and similar structures, and all places not accessible to the roller, or in such locations as will not allow thorough compaction with the rollers, shall be thoroughly compacted with lightly-oiled tamps.

5. Measurement. Asphaltic Concrete Surface Rehabilitation will be measured by the square yard of surface area of completed and accepted work of the depth shown on the plans.

6. Payment. The work performed and material furnished as prescribed by this item and measured as provided under "Measurement" will be paid for at the unit price bid for "Asphaltic Concrete Surface Rehabilitation", of the depth shown, which price shall be full compensation for cleaning existing pavement, all heating and scarifying, blending additional material and relaying of scarified materials; and for all manipulations, labor, tools, equipment and incidentals necessary to complete the work.